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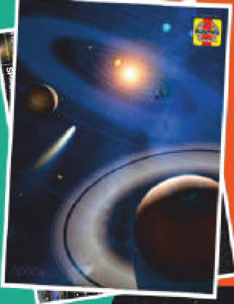

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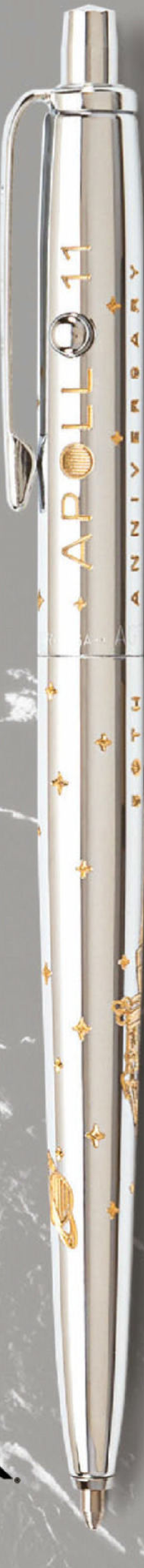

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Comets are seen today as harbingers of destruction, but could they have delivered life to Earth?

Welcome

If, like me, you're a keen observer of the night sky, then you have more than likely welcomed the longer, darker nights as we head deeper into autumn towards winter. It's not yet cold enough to prompt me to reach for a hot drink to keep warm during my observations, but the evenings have left me planning my next tour of the world's dark-sky parks. This issue we've shortlisted the best ones all over the world, so why not pick your nearest - or, if you're feeling adventurous, your farthest! - and plan your next astronomy adventure with us? There's plenty to explore!

And, just as there's a treasure trove of astronomical targets to be picked out with the naked eye, binoculars and telescopes over the coming months, there's plenty to keep you updated on the latest discoveries, mysteries and hottest news from around the universe this issue - from new research on some 'hidden' planets in our Solar System to the hunt for Earth's sister to how we'll build an internet network on the surface of Mars to the dating of a star that's been dubbed older than space and time itself.

That's not all - as usual we feature our readers' best astrophotography, discover why Venus has such a wild climate and reveal the inner workings of one of NASA's headline spacecraft, Juno, now in its third year of orbiting Jupiter.

Enjoy the issue - I'll see you again next month!

Gemma Lavender
Editor-in-Chief

Our contributors include...

Ian Evenden
Space science writer
The hunt for Earth 2.0 is still very much on, and scientists believe that a soon-to-be-launched mission could be our best chance of finding it. Head to page 38

Sebastian Gomez
Astrophysicist
Sebastian and scientists from the ESA, NASA and elsewhere answer your space questions this issue. Discover more on page 70

Tiffany Francis
Astronomy writer
In her interview with **All About Space**, Tiffany reveals how humanity is losing its connection with the night sky and how we can regain it once and for all

Lee Cavendish
Staff Writer
Where did life come from: comets or asteroids? In his special report, Lee reveals how the first organisms emerged following strikes from space rocks

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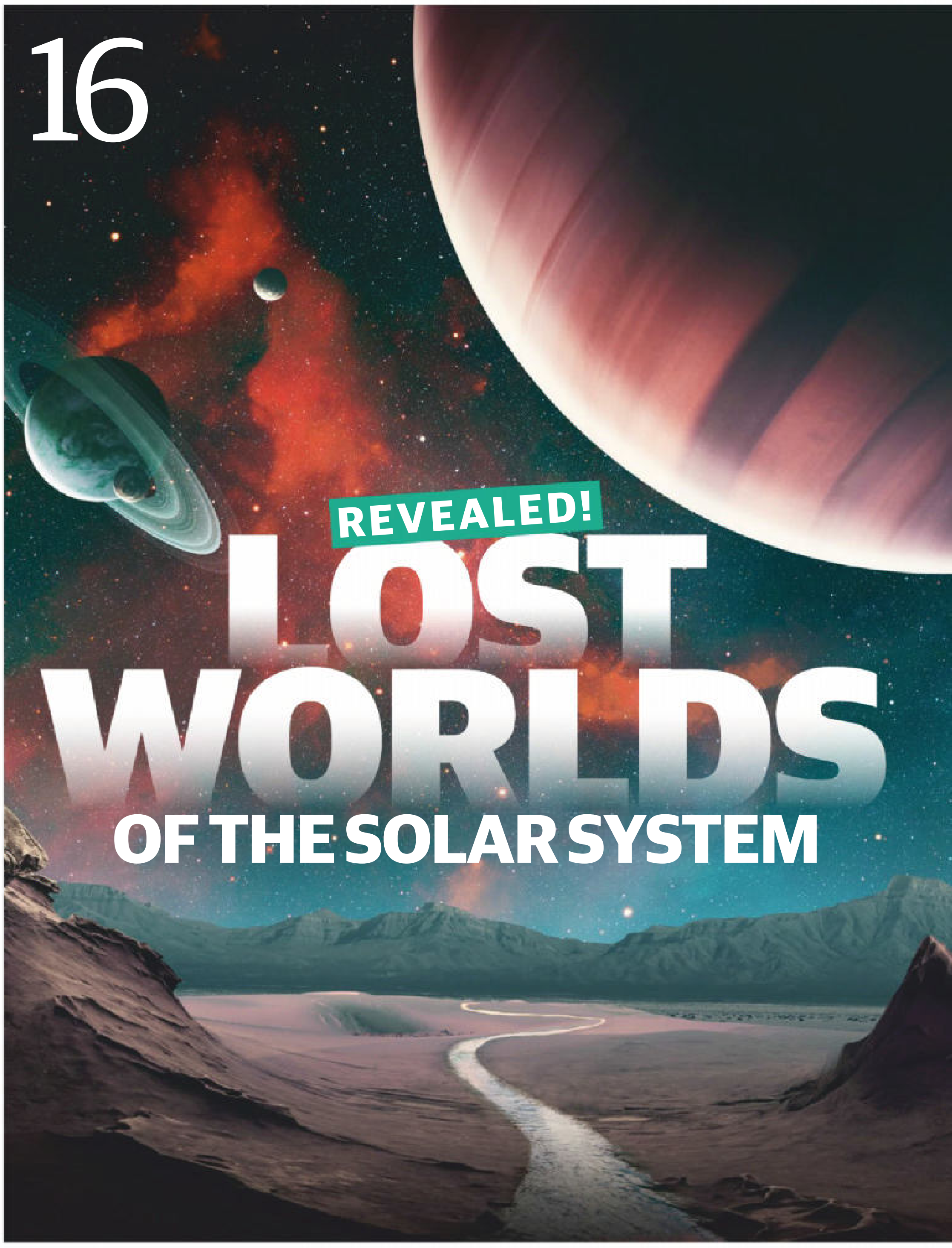
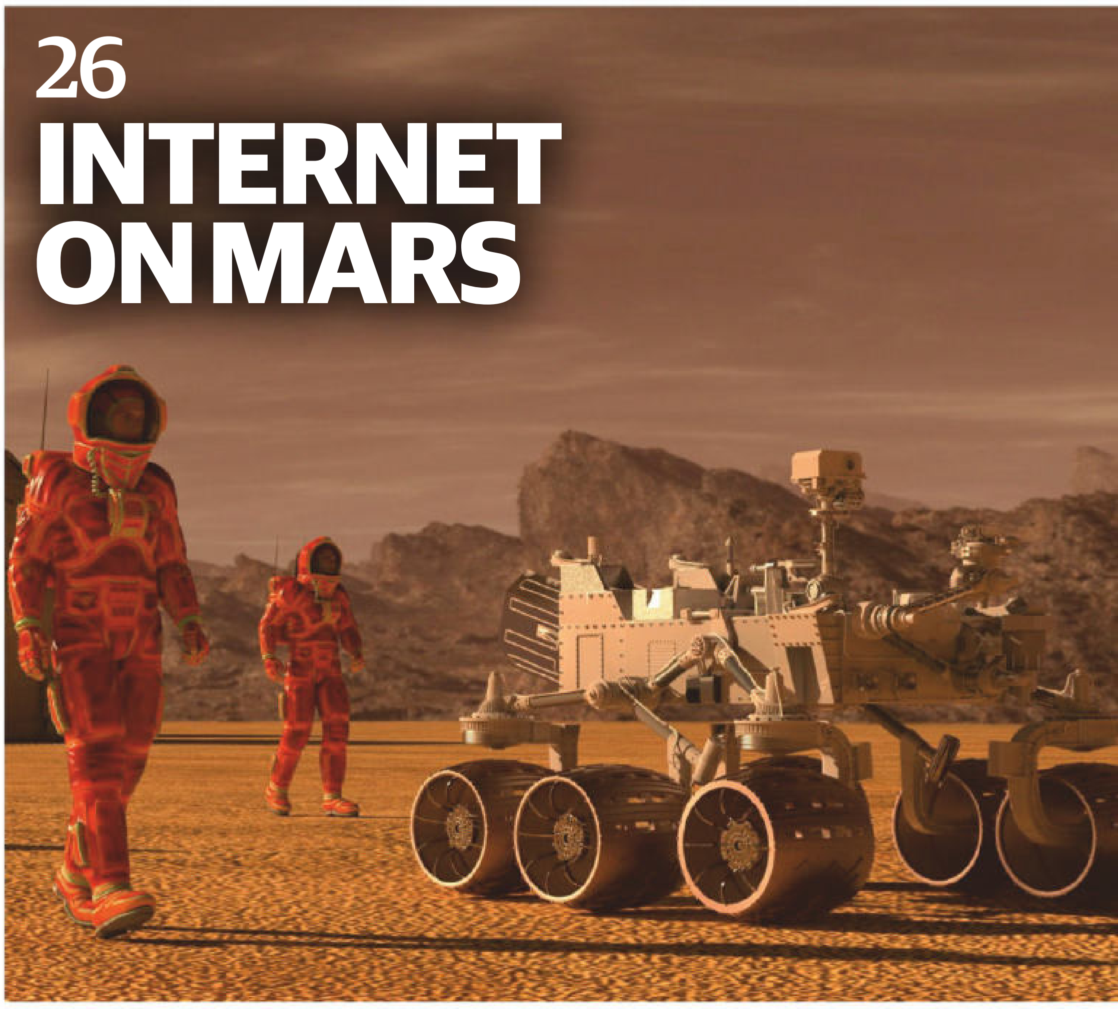
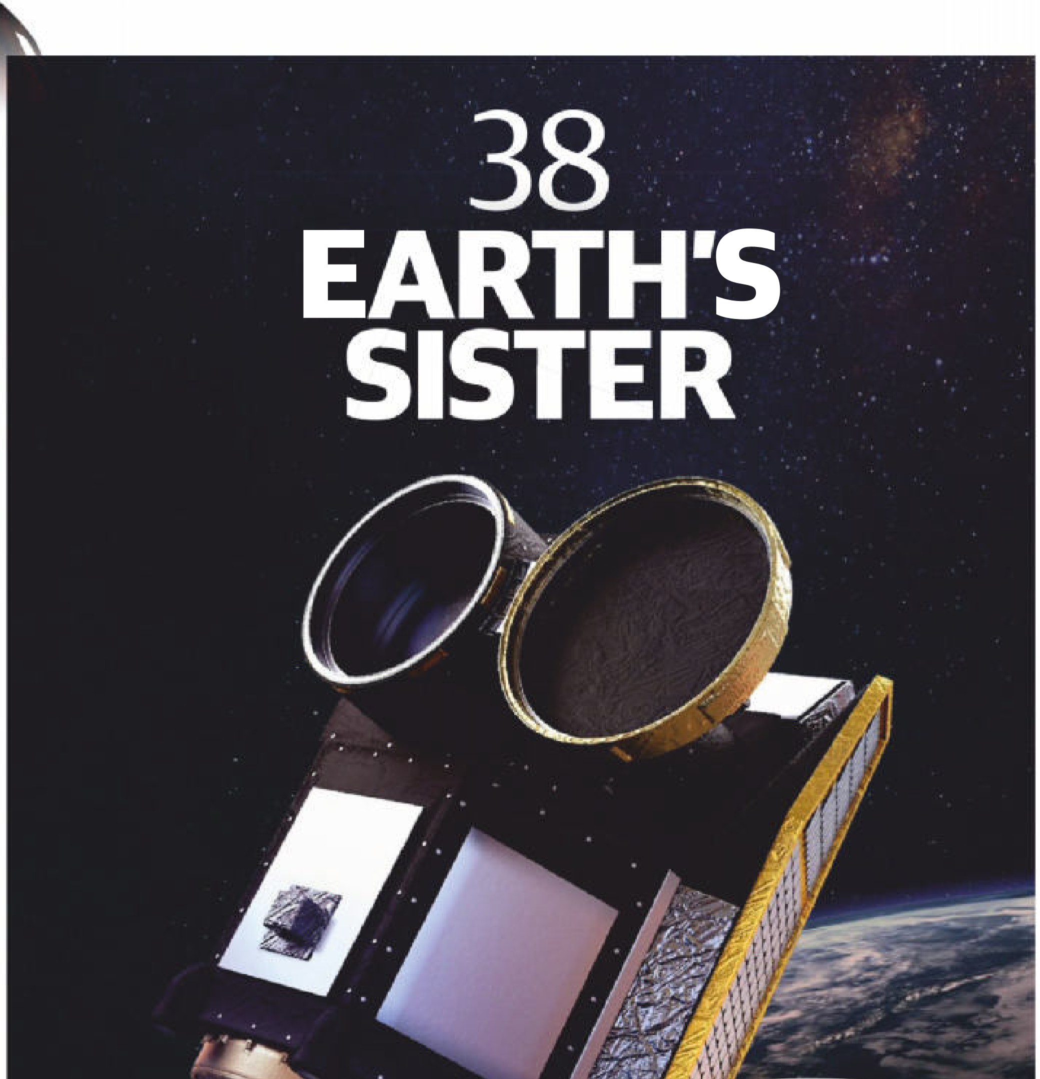




> “I realised how much I enjoyed being out on my own at night and the peace and solitude of it”

34 Tiffany Francis, author of *Dark Skies: A Journey into the Wild Night*



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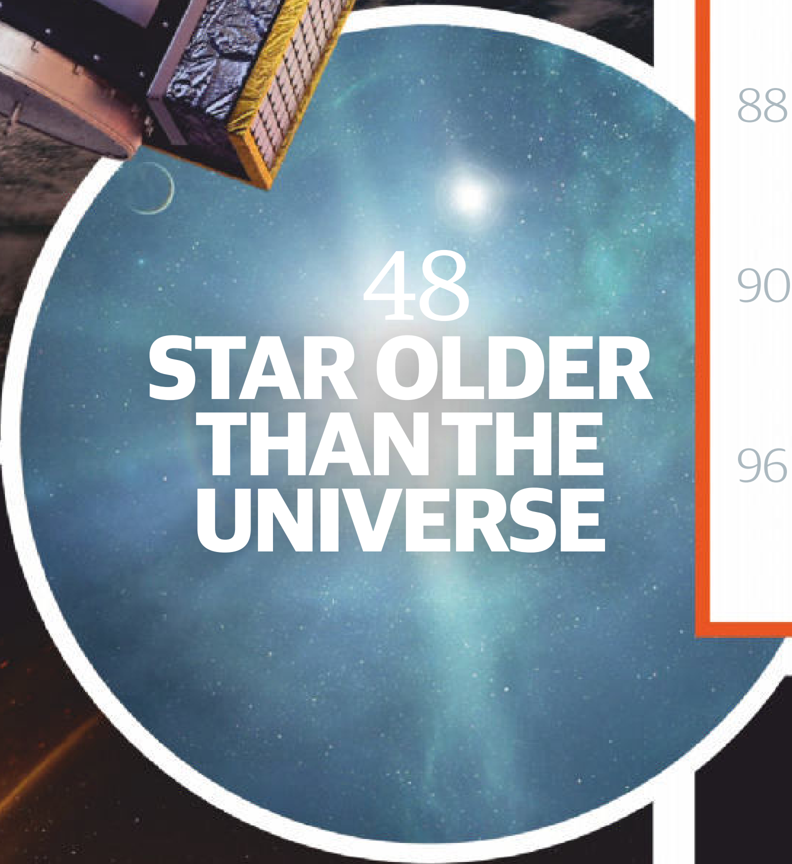

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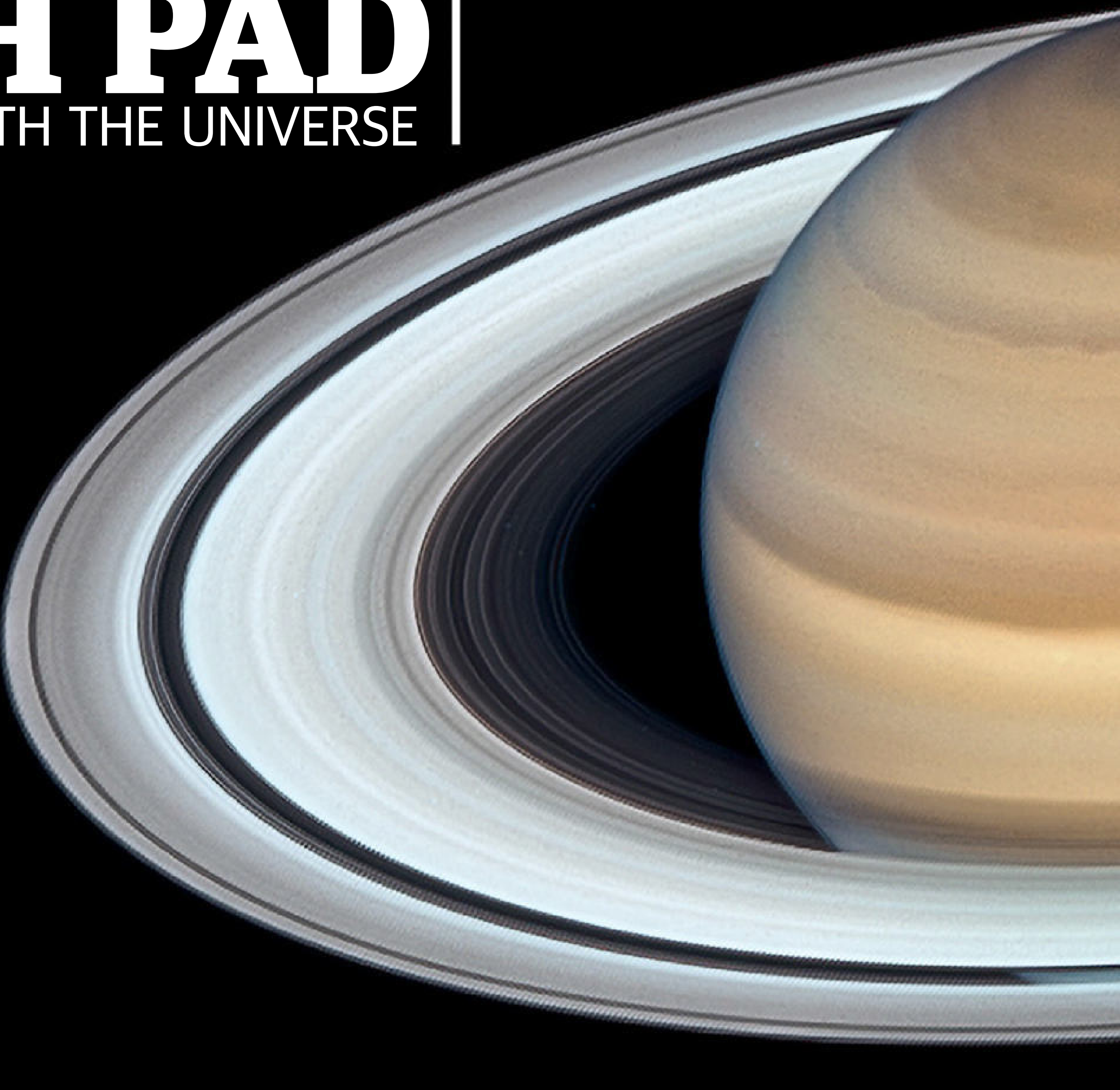

Saturn seen through the eyes of Hubble

This high-resolution picture of the Solar System's second-largest planet boasts a spectacular view of its 'crowning glory'. Paired with its icy ring structure, the hexagonal storm that swirls in Saturn's northern hemisphere is immediately obvious, along with several shades of amber stretching across its face. The hexagonal feature at the top of Saturn is so large that it is capable of fitting four Earths inside it without too much trouble!

Spinning a Mars rover on its back

As engineers continue to piece together NASA's next Martian explorer, the Mars 2020 rover, they took it for a spin in the Spacecraft Assembly Facility at NASA's Jet Propulsion Laboratory in Pasadena, California.

While spinning clockwise and counter-clockwise at a speed of one revolution per minute, engineers examined the rover for its centre of gravity, trying to decipher how the weight of the 1,040-kilogram (2,300-pound) vehicle is distributed in an attempt to balance it out. Determining the centre of gravity is a vital test, essential in making sure the spacecraft reaches the Red Planet safely and securely.

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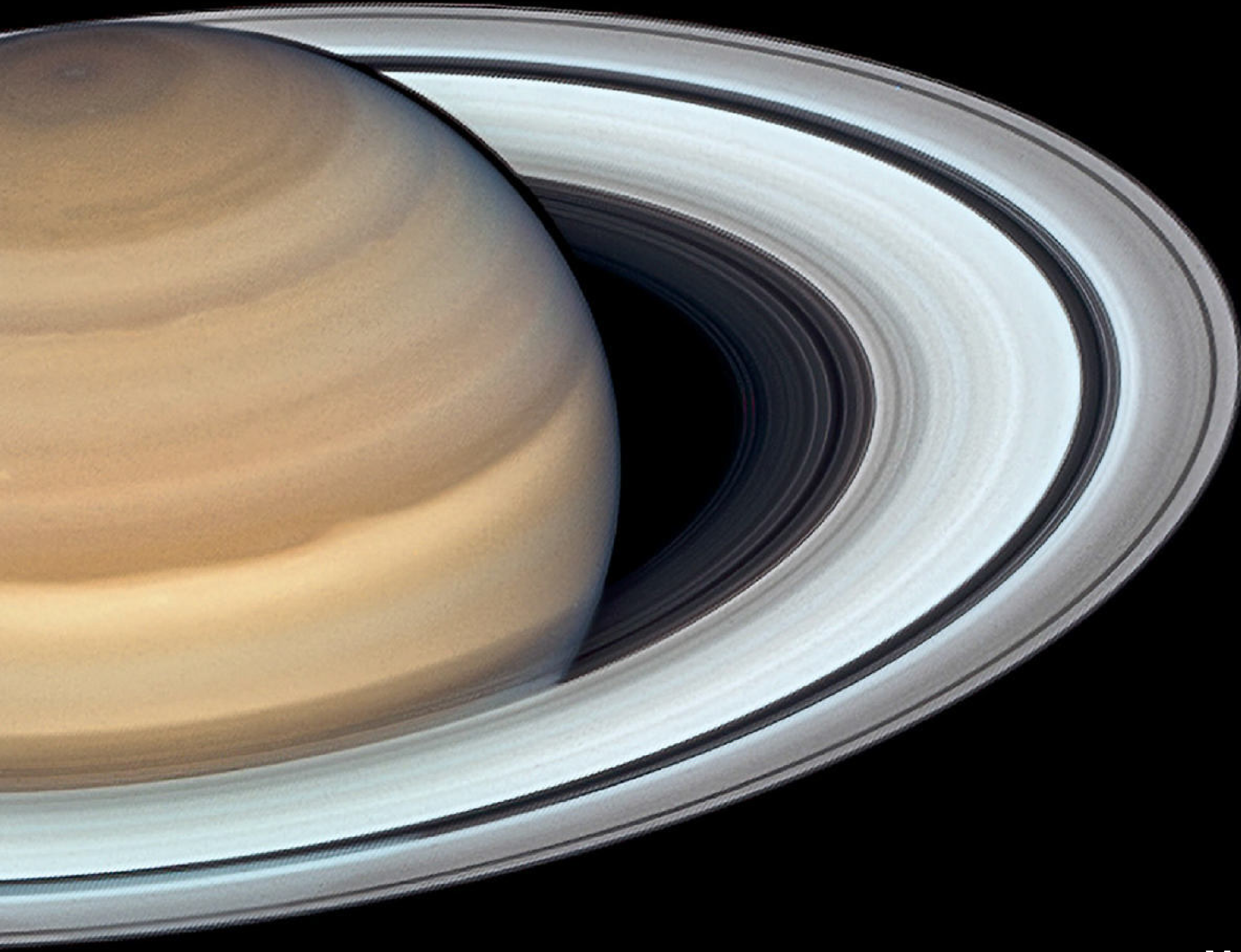

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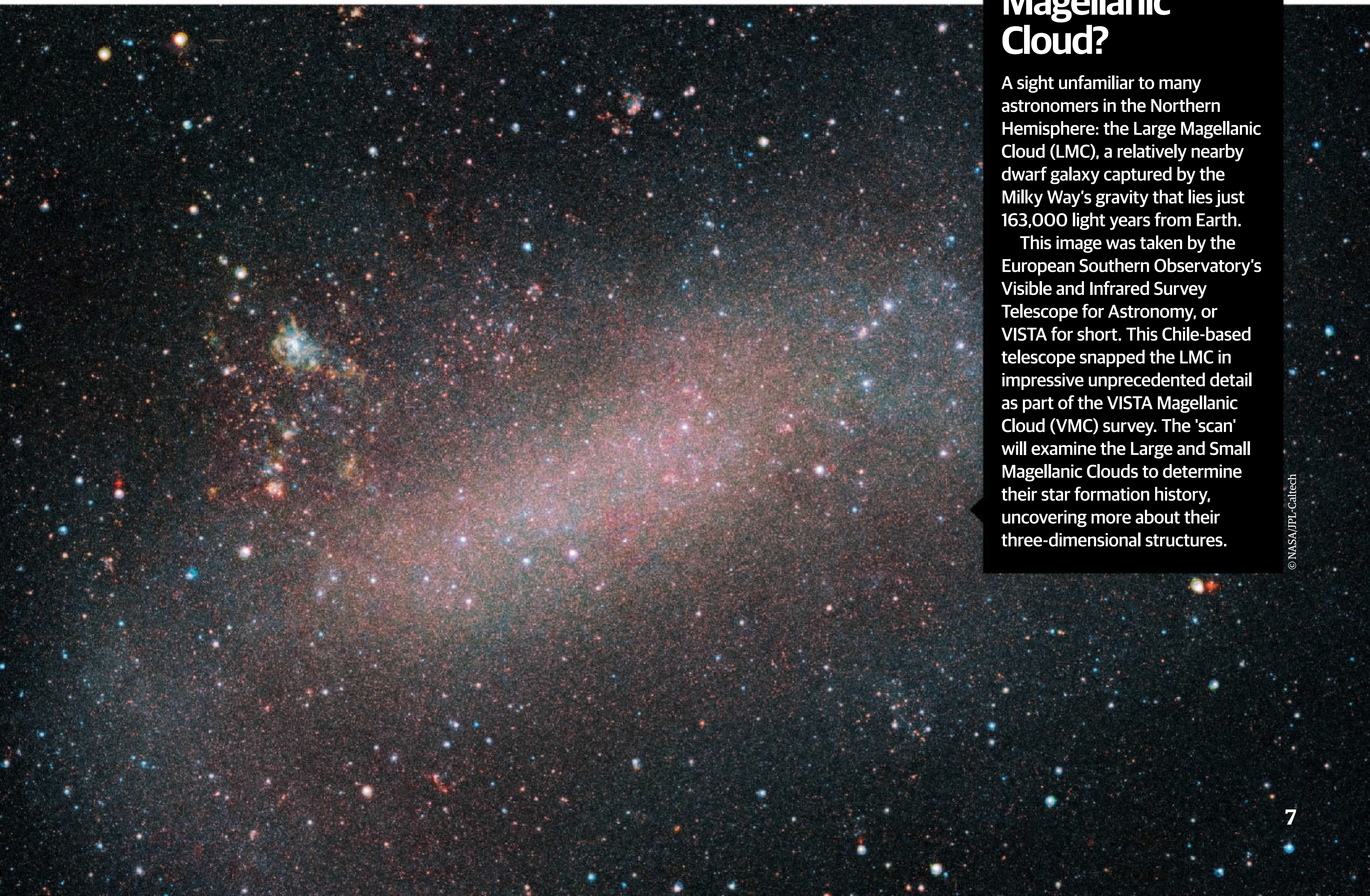

What secrets lie in the Large Magellanic Cloud?

A sight unfamiliar to many astronomers in the Northern Hemisphere: the Large Magellanic Cloud (LMC), a relatively nearby dwarf galaxy captured by the Milky Way's gravity that lies just 163,000 light years from Earth.

This image was taken by the European Southern Observatory's Visible and Infrared Survey Telescope for Astronomy, or VISTA for short. This Chile-based telescope snapped the LMC in impressive unprecedented detail as part of the VISTA Magellanic Cloud (VMC) survey. The 'scan' will examine the Large and Small Magellanic Clouds to determine their star formation history, uncovering more about their three-dimensional structures.

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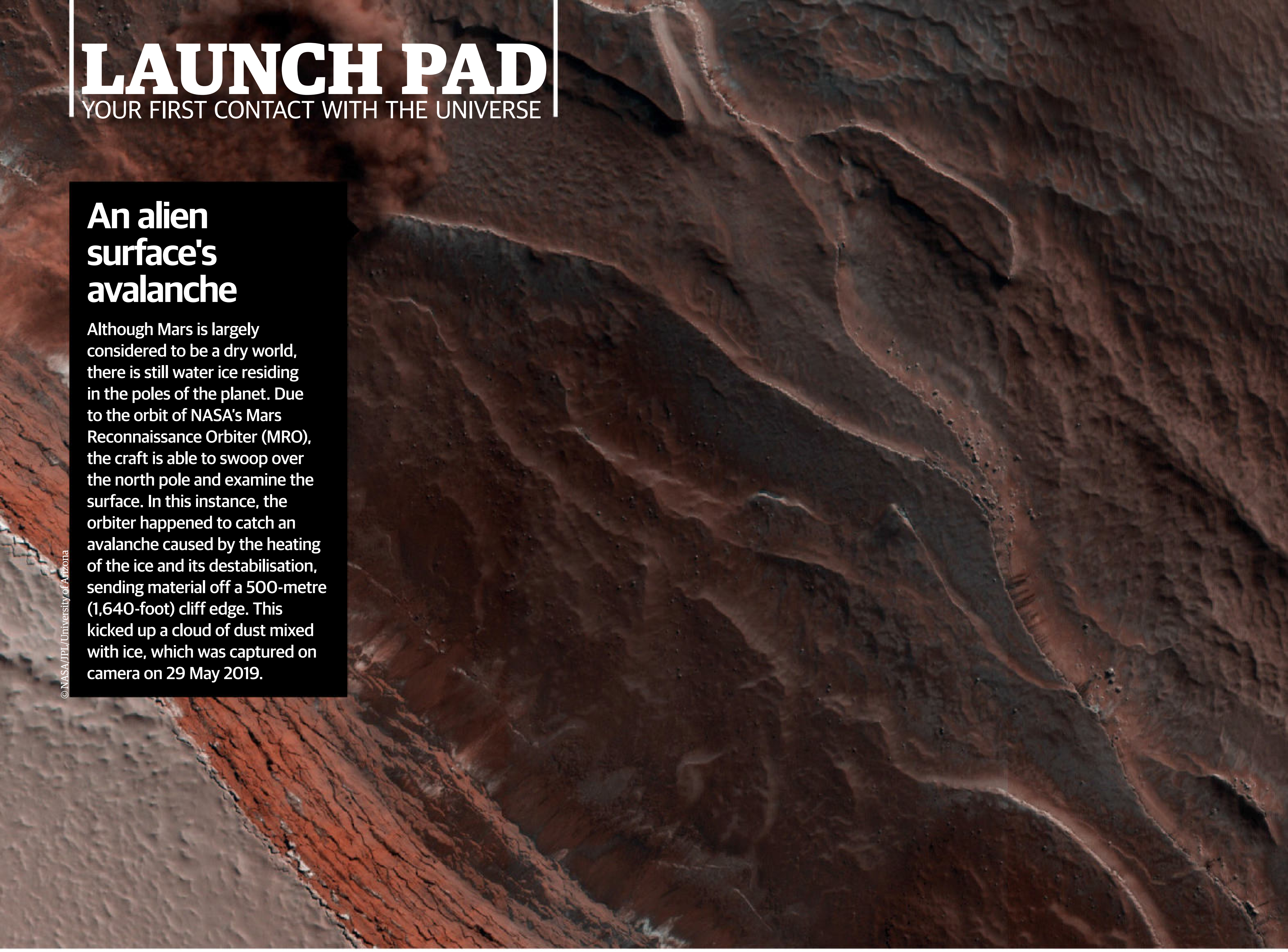


An alien surface's avalanche

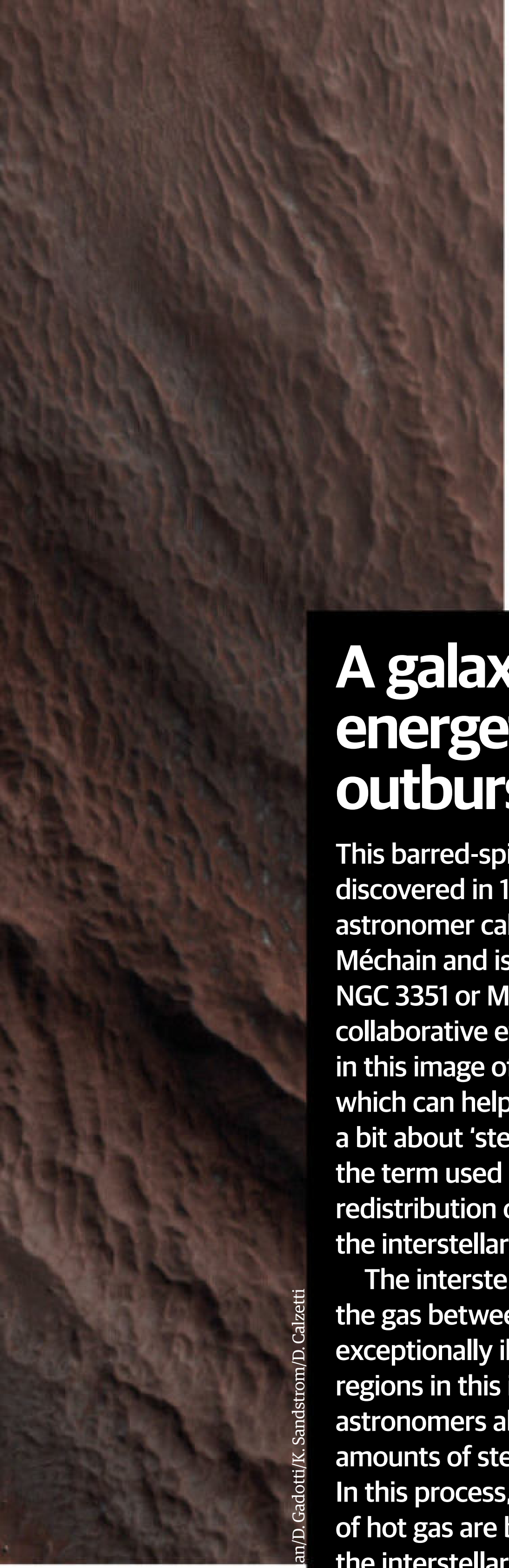
Although Mars is largely considered to be a dry world, there is still water ice residing in the poles of the planet. Due to the orbit of NASA's Mars Reconnaissance Orbiter (MRO), the craft is able to swoop over the north pole and examine the surface. In this instance, the orbiter happened to catch an avalanche caused by the heating of the ice and its destabilisation, sending material off a 500-metre (1,640-foot) cliff edge. This kicked up a cloud of dust mixed with ice, which was captured on camera on 29 May 2019.

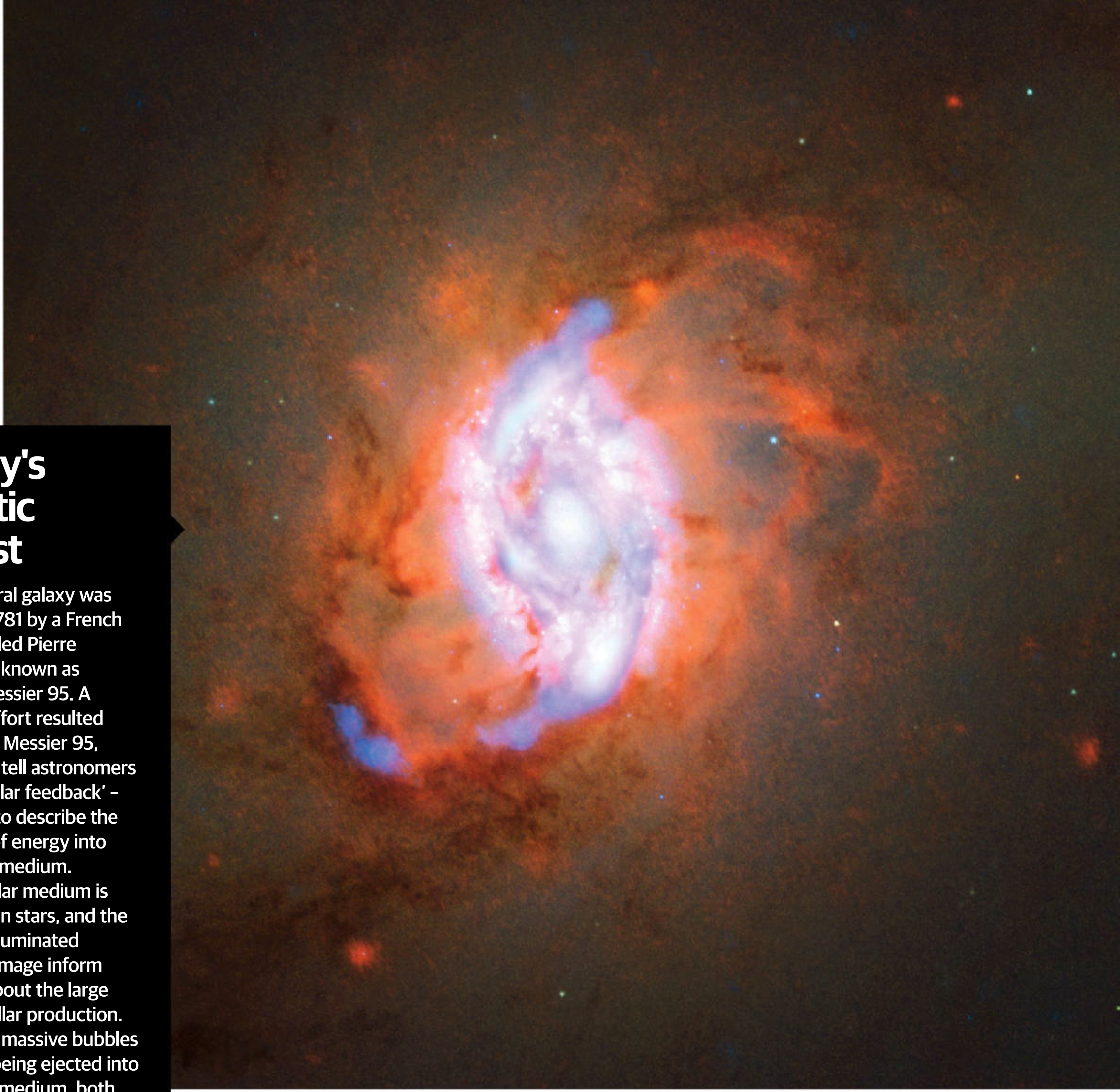
© NASA/JPL/University of Arizona

Diving into caves will help explore space

The European Space Agency (ESA) has put together a creative and innovative training course that will help develop important astronautic skills. It is known as the Cooperative Adventure for Valuing and Exercising human behaviour and performance Skills, or CAVES, training course.

For three weeks astronauts – or 'cavenauts' – will conduct real science experiments and operations in order to improve their communication, problem-solving and teamwork skills. This course will try its best to mirror life on board the International Space Station without actually going into space.





A galaxy's energetic outburst

This barred-spiral galaxy was discovered in 1781 by a French astronomer called Pierre Méchain and is known as NGC 3351 or Messier 95. A collaborative effort resulted in this image of Messier 95, which can help tell astronomers a bit about 'stellar feedback' – the term used to describe the redistribution of energy into the interstellar medium.

The interstellar medium is the gas between stars, and the exceptionally illuminated regions in this image inform astronomers about the large amounts of stellar production. In this process, massive bubbles of hot gas are being ejected into the interstellar medium, both hindering and encouraging the birth of stars.

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Astronauts: present visits the past

Ahead of Expedition 61, which signals over 60 missions to the International Space Station, the backup crew paid a visit to some of the sights in Baikonur, Kazakhstan. Here, they took a picture with a true innovator in their profession: Yuri Gagarin – the first person in space. The backup crew members consist of, from right to left, Tom Marshburn of NASA, Sergey Ryzhikov of Roscosmos and Sultan Al-Neyadi of the United Arab Emirates (UAE). Al-Neyadi is one of the first two astronauts from the UAE, the other being Hazza Al Mansouri.

© NASA/Victor Zelentsov

Making the jump to light speed

This image bears a remarkable resemblance to *Star Wars* as the crew of the Millennium Falcon made the jump to light speed, the dots of light beginning to streak across the screen. Sadly, nothing quite as exciting is happening in this image – no one is jumping in their spacecraft and gearing up to travel at light speeds to the centre of the Milky Way.

In fact, this was taken by astronomers at the European Southern Observatory, who captured this view of our marvellous galaxy using a zooming technique, revealing its band of illuminated dust, whilst having starlight streak across the view.

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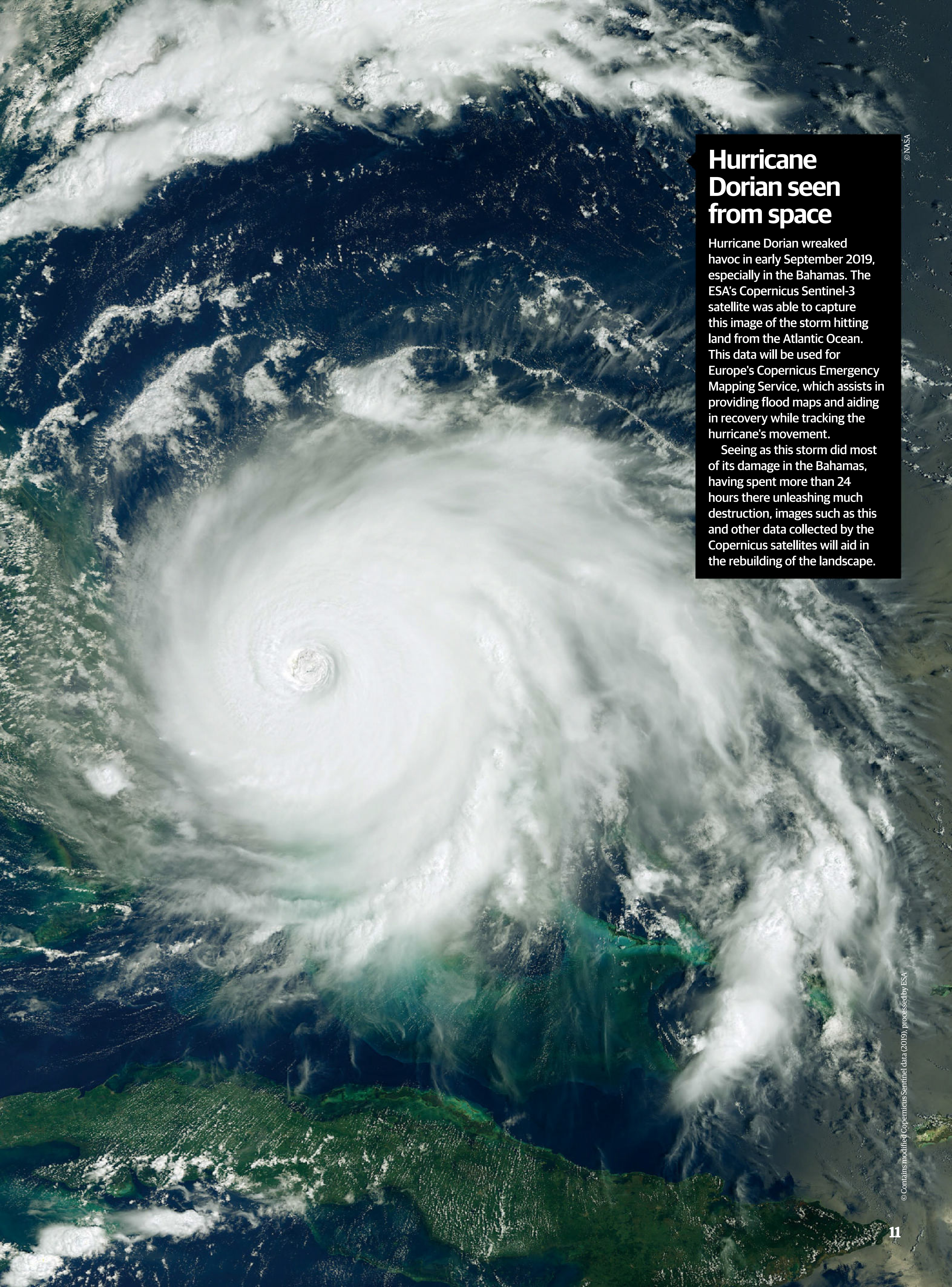

Hurricane Dorian seen from space

Hurricane Dorian wreaked havoc in early September 2019, especially in the Bahamas. The ESA's Copernicus Sentinel-3 satellite was able to capture this image of the storm hitting land from the Atlantic Ocean. This data will be used for Europe's Copernicus Emergency Mapping Service, which assists in providing flood maps and aiding in recovery while tracking the hurricane's movement.

Seeing as this storm did most of its damage in the Bahamas, having spent more than 24 hours there unleashing much destruction, images such as this and other data collected by the Copernicus satellites will aid in the rebuilding of the landscape.

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© Contains modified Copernicus Sentinel data (2019), processed by ESA

It's gonna blow! Giant volcano on Jupiter moon could erupt any day

Words by **Mike Wall**

The biggest volcano on Io should erupt any day now, a new study suggests. Loki Patera, a 200-kilometre (125-mile) wide lava lake on the most volcanically active body in the Solar System, has had fairly regular activity over the past few decades. And it's due for an outburst very soon. "If this behaviour remains the same, Loki should erupt in September 2019, around the same time as the EPSC-DPS meeting in Geneva," Julie Rathbun, a senior scientist at the Planetary Science Institute in Tucson, Arizona, said in a statement on 17 September. "We correctly predicted that the last eruption would occur in May of 2018."

EPSC-DPS is a joint conference held by the European Planetary Science Congress and the American Astronomical Society's Division for Planetary Sciences. Rathbun presented the new results at the 17 September meeting.

Scientists aren't sure what drives Loki Patera's outbursts, but the leading explanation posits a process very different than what's behind typical volcanic eruptions here on Earth: the top layer of Loki Patera solidifies, then falls into the still-liquid portion below.

And the intrigue surrounding Loki Patera doesn't stop there; the periodicity of the lake's eruptions has changed over the decades as well. The outbursts occurred every 540 Earth days or so in the 1990s. The periodic behaviour seemed to stop in the early 2000s but reappeared around 2013, with eruptions now happening roughly every 475 days. Given all these shifts and uncertainties, Rathbun isn't exactly betting the farm on a Loki Patera flare-up in the next few days.

"Volcanoes are so difficult to predict because they are so complicated. Many things influence volcanic eruptions, including the rate of magma supply, the composition of the magma – particularly the presence of bubbles in the magma – the type of rock the volcano sits in, the fracture state of the rock and many other issues," Rathbun said in the same statement.

"We think that Loki could be predictable because it is so large," she added. "Because of its size, basic physics are likely to dominate when it erupts, so the small complications that affect smaller volcanoes are likely to not affect Loki as much. However, you have to be careful because Loki is named after a trickster god [of Norse mythology], and the volcano has not been known to behave itself."

Loki Patera's activity cycle is far too lengthy to be tied to Io's orbit around Jupiter, which is supertight; the moon completes one lap every 1.77 Earth days. Researchers think that gravitational interactions among Io and some of its fellow moons may be responsible for the semi-regularity. Jupiter's powerful gravity is the root cause of Io's volcanism overall, however. The planet's constant tug stretches Io's innards, melting moon rock into magma via tidal heating.

Io is the most volanically active body in the whole Solar System

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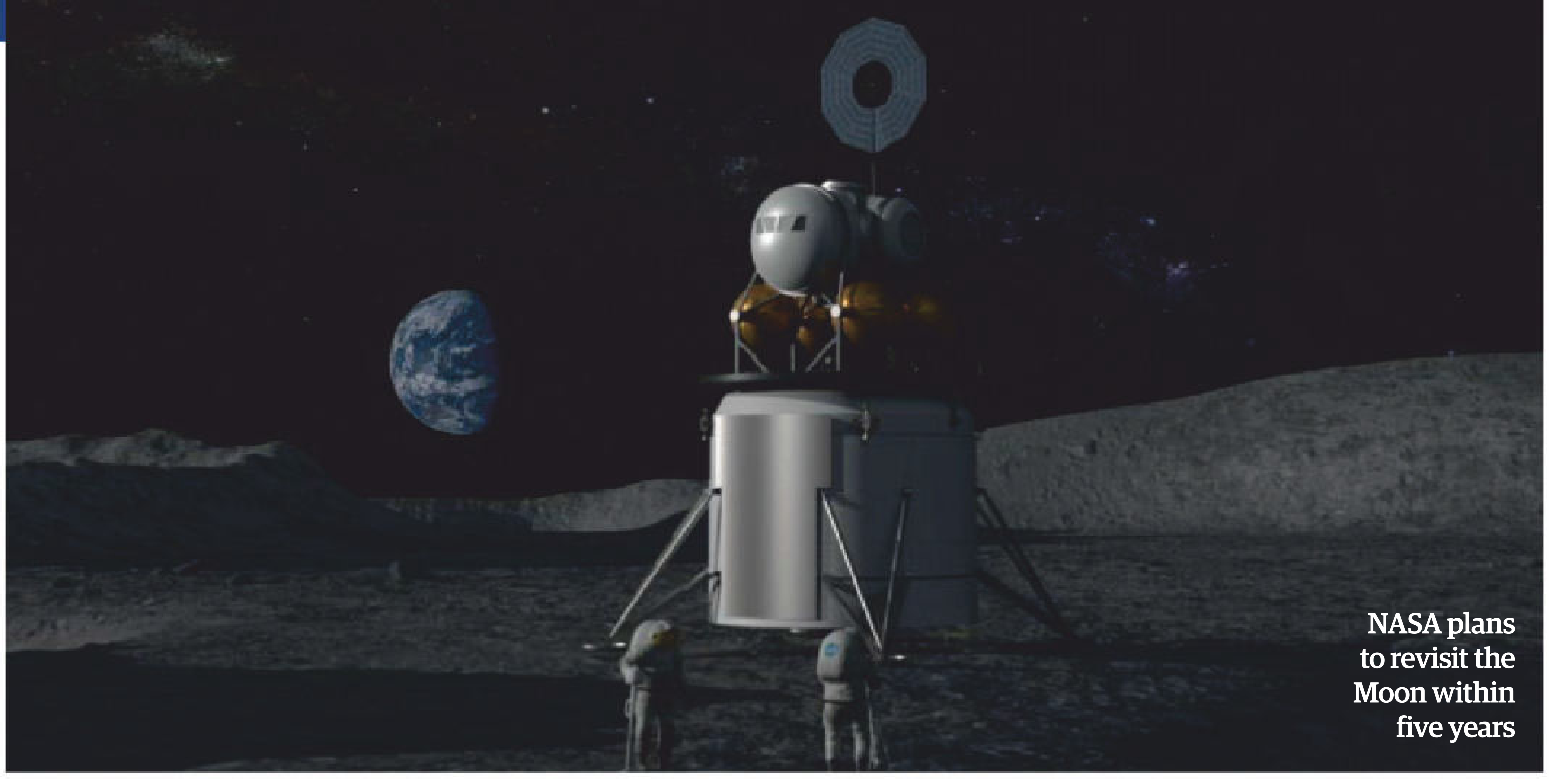
NASA plans to revisit the Moon within five years

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NASA targets second half of 2024 for human Moon landing

Words by **Meghan Bartels**

For six months NASA has been chasing big plans to land humans near the south pole of the Moon in 2024. That deadline came from vice president Mike Pence in March and represented a significant increase in speed from the human Moon landing's previous timeline, targeting 2028. The project has since been dubbed the Artemis program, a nod to the fact that NASA plans to include a female astronaut in the Moon landing for the first time. But despite the pressured schedule, NASA wasn't specific about when in 2024 it hopes to accomplish the feat.

On 12 September the agency offered its first hint when Greg Chavers, acting deputy program manager for human landing system at NASA's Marshall Space Flight Center, spoke during a panel held in Huntsville, Alabama. "We all know 2024 is the big date; we don't have a specific day that's codified yet," Chavers said. "We're targeting sometime in the last half of 2024. That gives us a little more time."

NASA has plenty of projects it needs to accomplish in that time, however. The massive Space Launch System rocket planned for use in the mission is not ready to fly, the Orion capsule has never flown a crewed mission, the agency will need new spacesuits designed for the lunar surface and the plan that allows astronauts to land near the south pole requires the construction and maintenance of a Gateway waystation in orbit of the Moon.

To accommodate the shortened schedule, Chavers and his colleagues have tweaked some of the requirements and plans for projects they are running in association with the push to return to the Moon. "We're running really fast," Chavers said. "It's uncomfortable for many of us, but we're excited about it."

Saturn's rings may be ancient after all

Words by **Mike Wall**

For years scientists have argued about the age of Saturn's famous rings: are they ancient, dating to the birth of the planet itself? Or did the ring system form more recently?

This latter hypothesis has been gaining steam in the last few years, with multiple papers reporting that the rings could be even younger than the dinosaurs. Such studies cite the rings' composition – more than 95 per cent pure water ice – and total mass, which NASA's Cassini mission pegged at about 15.4 million billion metric tons shortly after the probe's epic 'grand finale' at Saturn in 2017. For perspective, 15.4 million billion metric tons is about 40 per cent the mass of the Saturn moon Mimas, which is 400-kilometres (250-miles) wide.

Given these two figures, and the bombardment rate by micrometeoroids, the rings must be young, the idea goes. After all, old rings should be much more 'polluted' with silicates, organic molecules and other compounds.

But there are some serious issues with this interpretation, argues the new study, which was led by Aurélien Crida of the Université Côte d'Azur and the Institut Universitaire de France. For starters, the scientists said, the bombardment rate may vary over time. Maybe it's unusually high right now – due to a hypothetical recent collision of distant Kuiper Belt objects, for example – and the rings were polluted much less intensely for most of their history.

Crida and his colleagues also note that during the grand finale, Cassini spotted organics in Saturn's upper atmosphere as well as solid grains in the gap between the gas giant and its innermost ring. This stuff is almost certainly coming from the rings, the researchers said.

"One possible explanation is that the unknown process responsible for the erosion of the rings and the launch of these nanograins is actually 'cleaning' the rings, preferentially removing silicates rather than water ice," Crida and his team wrote in the new study, which was published in the journal *Nature Astronomy*. If that's the case, the rings would appear to be much younger than they actually are.

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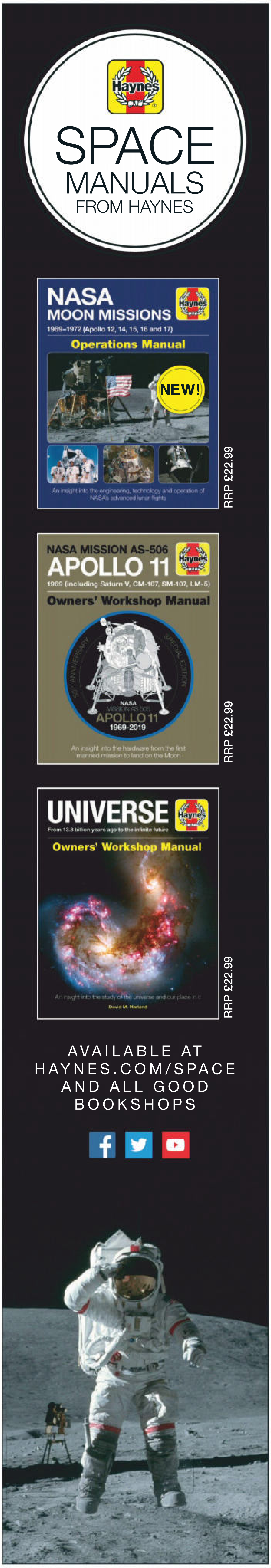
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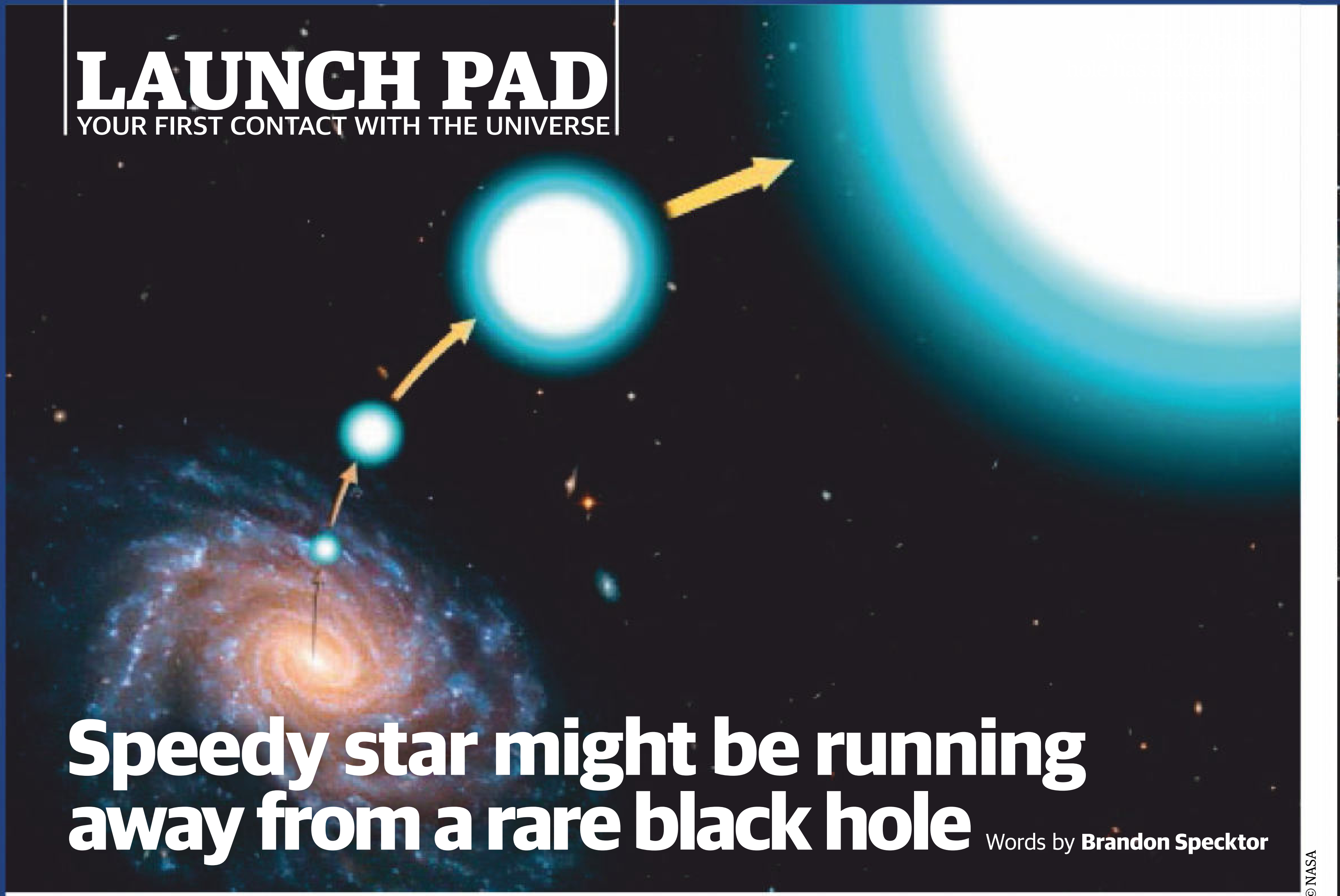

Speedy star might be running away from a rare black hole

Words by **Brandon Specktor**

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According to a study published 6 August in the journal *Astronomy & Astrophysics*, it seems a young star is running away from a hungry black hole. The star, named PG 1610+062, was first observed hurtling across the sky in a 1986 star survey. Astronomers working at the W. M. Keck Observatory atop Hawaii's Mauna Kea took the closest-ever look at the runaway. They confirmed it is one of the fastest stars ever seen shooting out of the Milky Way's galactic disc.

The team calculated the star's velocity to be about 2 million kilometres (1.2 million miles) per hour, which isn't quite enough to escape the bonds of the galaxy's gravity, but fast enough for it to be able to leave the star's home solar system in the cosmic dust.

There are a few different processes that explain how a star can get booted out of its home system, and they usually involve binary partnerships – two stars orbiting around a common centre of mass. If one member of the pair was to theoretically disappear – by exploding in a supernova or getting swallowed up by a black hole – the remaining star might get such a sudden, energetic kick that it would slingshot straight out of its home system, or even out of its home galaxy entirely.

The case of PG 1610+062 may be a bit unusual though, the researchers wrote. Judging by the star's mass, velocity and likely origin – the team traced it to the Sagittarius spiral arm of the galaxy – it seems unlikely that the star ever came close enough to the supermassive black hole at the centre of our galaxy to see its partner star gobbled up. The star's semi-speedy movement seems to suggest that it had a run-in with a mid-mass black hole, according to NASA.

Scientists have never found convincing evidence that mid-mass black holes exist in our galaxy. This stellar runaway still isn't hard proof of their existence, but it does strengthen the case that mid-mass black holes could be out there, the researchers wrote.

Astronomers get the goods on Jupiter-smacking space rock

Words by **Mike Wall**

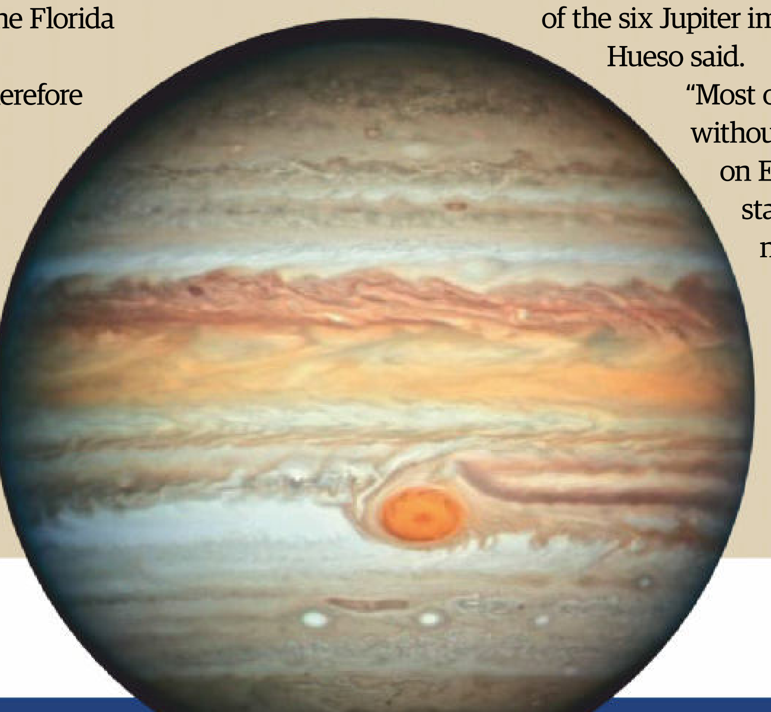
Something slammed into the king of planets on 7 August, generating a flash that was spotted by Texas-based amateur astronomer Ethan Chappel. Now, six weeks later, astronomers have put together a sketch of the assailant.

The impactor was likely 12 to 16 metres (39 to 52 feet) wide, with a mass of around 408 metric tons (450 tons), according to analyses conducted by Ramanakumar Sankar and Csaba Palotai of the Florida Institute of Technology.

The object's density was therefore similar to that of stony-iron meteorites, suggesting the impactor was an asteroid rather than a comet. The asteroid broke apart about 50 miles (80 kilometres) above Jupiter's cloud tops, unleashing the energetic equivalent of 240 kilotons of TNT, Sankar and Palotai found. That's about half as energetic as the February 2013 airburst over the Russian city of Chelyabinsk, which was caused by a 20-metre (65-foot) wide meteor.

Ricardo Hueso, a researcher at the University of the Basque Country, also analysed the impact data and came to similar conclusions about the asteroid's size and mass. The August event was likely the second brightest of the six Jupiter impacts observed since 2010, Hueso said.

"Most of these objects hit Jupiter without being spotted by observers on Earth," Hueso said in a statement. "However, we now estimate 20 to 60 similar objects impact with Jupiter each year. Because of Jupiter's large size and gravitational field, this impact rate is 10,000-times larger than the impact rate of similar objects on Earth."



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'Fireworks galaxy' is exploding in X-ray light, and scientists are confused

Words by **Brandon Specktor**

The Fireworks Galaxy is exploding. To be fair, it's been exploding for a while, at least since 1917 – give or take the 25 million years that light takes to travel from that galaxy to Earth – when astronomers first glimpsed a large star erupting into a supernova there. Since then scientists have detected nearly a dozen stellar explosions in the busy galaxy, but none quite like the mysterious green blotch of X-ray light visible in the image above.

What makes that blotch special? For starters, it's not a supernova. The X-ray signature detected by NASA's Nuclear Spectroscopic Telescope Array (NuSTAR) is far more energetic than that of a typical supernova. The energetic X-ray blast also appeared and disappeared from the galaxy in about ten days – a much briefer appearance than a supernova, which can brighten and fade over hundreds of days.

A study published 9 August in *The Astrophysical Journal* provides a few guesses to what it might be. The study authors, who glimpsed the mysterious blast of energy by chance while studying supernovae in the galaxy, said the mystery explosion likely involves one of the most powerful objects in the universe, possibly a black hole or neutron star, tearing apart one of its neighbours.

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REVEALED!

LOST WORLDS OF THE SOLAR SYSTEM

Reported by Giles Sparrow

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Do new discoveries about our neighbouring planets reveal rogues that caused chaos in the early years of our cosmic backyard?

Our Solar System usually feels like a fairly orderly place. Eight planets orbit the Sun on more or less circular paths along with two broad belts of smaller objects, the Asteroid and Kuiper Belts. Only a few stray objects – rocky near-Earth asteroids and icy comets and centaurs – stray onto wilder paths. Their encounters with the larger worlds can have violent consequences for planetary surfaces, but in the long run the planets themselves remain unaffected.

Recently, however, astronomers have been questioning whether it's always been this way, with evidence from computer models, improved understanding of our neighbouring planets and studies of other solar systems with very different configurations all pointing to a secret wild past.

It's increasingly clear that our Solar System had a rebellious youth in which planets could switch orbits and undergo traumatic close encounters. But some researchers go even further, suggesting that the solutions to some major mysteries of the present-day planets lie in the influence of bodies that have since disappeared entirely from the family of the Sun – the lost worlds of our Solar System's deep history.

"I think it's human nature to look at things and assume that what you see was there since forever,"

© Tobias Roetsch

The early Solar System was a chaotic place of collisions

says astronomer David Nesvorny of the Southwest Research Institute in Boulder, Colorado. "A good example is Einstein, who thought that the universe should be static. It is a good starting point to adopt this unchanging view, but things often turn more complicated than it seems. The more planetary scientists dig into the past of the Solar System, the more complicated the picture that emerges."

This revolution in the understanding of our Solar System's dynamic history began in the early 2000s through the work of a group of astronomers centred on the Observatory of the Côte d'Azur near Nice, France. Inspired by the recent discovery of gas giant exoplanets orbiting very close to distant stars in orbits where, according to established models, no such planets could ever have formed, they began to investigate the possibility that planets in our Solar System could have migrated through their history to reach their present, relatively stable orbits. Alongside this they embraced the concept of mathematical chaos - the idea that the complex gravitational relationships between the Sun and major planets are so intricate that on billion-year timescales many orbits that appear stable are actually prone to unpredictable, dramatic changes.

In 2005 the Côte d'Azur researchers published a trio of papers outlining what is now known as the 'Nice model' - a new history of Solar System evolution in which the four outer giant planets formed considerably closer to the Sun than their present positions, then migrating outward through a series of interactions with each other and the countless small, icy comets that filled the region of their present-day orbits. For Saturn, Uranus and Neptune, encounters with comets worked a little like the gravitational slingshot manoeuvres used by artificial space probes - each one involved an exchange of orbital speed and energy that pushed the planet further out while dropping the comet a little further towards the Sun.

The Nice model solves some important questions about the formation of the planets. For instance, it does away with the need to spread a dense cloud of planet-forming ice and gas as far out as Neptune's present-day orbit. It also explains how encounters with Jupiter's powerful gravity finally 'cleared out' comets from its neighbourhood, flinging them into long orbits that stretch up to a light year from the Sun where they mostly remain today in the huge spherical shell known as the Oort Cloud. Along the way it makes some curious predictions, such as Uranus and Neptune briefly developing wild, chaotic orbits that ultimately caused them to switch places in the Solar System - under the influence of a gravitational tag-team during a brief phase when Saturn's orbit was precisely twice that of Jupiter.

Inspired by the many successes of the Nice model, many other astronomers have since considered whether migrating worlds could hold the solution to other planetary mysteries. In 2011 some of the original Côte d'Azur team produced a modified theory, known as the Grand Tack, in which Jupiter migrates first inwards, losing energy as it ploughs through gas left over from the Sun's formation before migrating outwards through interactions with comets. The Grand Tack, it's claimed, allows Jupiter's gravity to limit the growth

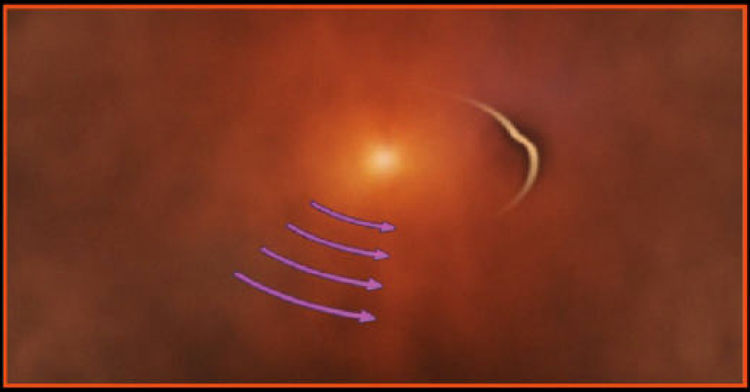
NASA's TESS is teaching us more about alien solar systems

© Tobias Roetsch

> "The more we dig into the past of the Solar System, the more complicated the picture that emerges" **David Nesvorny**

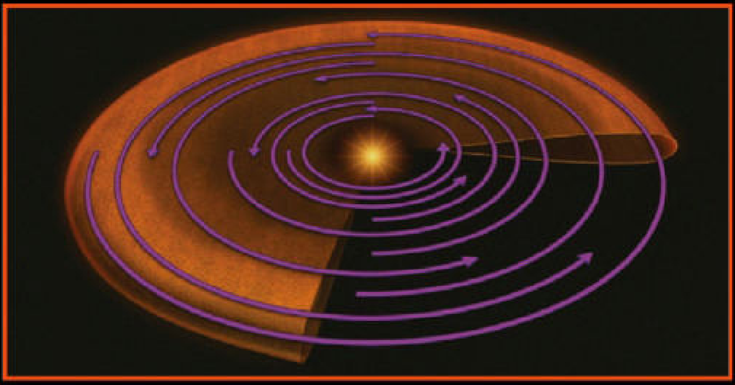
Making of our cosmic backyard

The formation of the Solar System would have produced many more large objects than the eight major planets and handful of dwarfs we know today



Collapsing cloud

The Solar System began when a huge cloud of interstellar gas and dust called a nebula began to collapse around 5 billion years ago. Knots of denser gas began to form in the cloud, and as their gravity grew stronger they separated into distinct globules that grew denser over time.

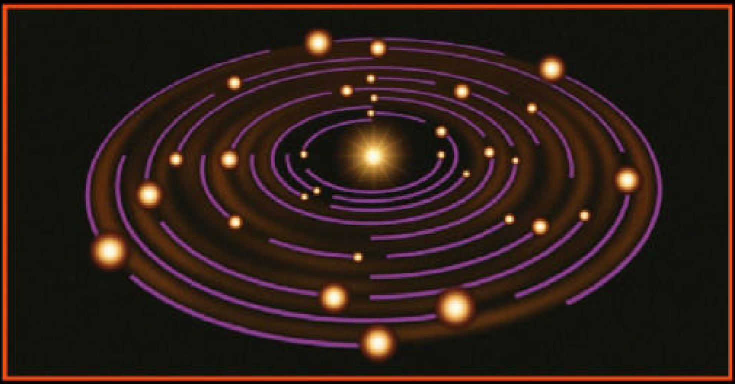


Protoplanetary nebula

As the globule became more concentrated towards the centre it span more rapidly, while collisions between clumps of gas and dust caused it to form a flattened disc. The Sun's radiation pressure halted the collapse and drove volatile materials away from the inner Solar System.

Planetary embryos

Solid dust grains in the rotating protoplanetary nebula began to collide and stick together. As they grew in size, the largest formed into clumps with enough gravity to pull in more material. They rapidly snowballed into Moon-sized planetary embryos, or 'planetesimals'.



Building the giants

In the outer Solar System, gas and volatile icy materials remained plentiful. The growing planetesimals pulled in huge amounts of these materials from their surroundings, piling up deep atmospheric envelopes and forming the larger planets.

Vulcanoids

Some astronomers speculate that small rocky objects known as vulcanoids, perhaps carrying remnants of primordial worlds, could still exist inside Mercury's close orbit.

Planet V

One theory to explain the relatively small size of Mars requires the existence of a substantial Planet V between Mars and the asteroid belt, whose orbit was later disrupted by Jupiter.

Theia

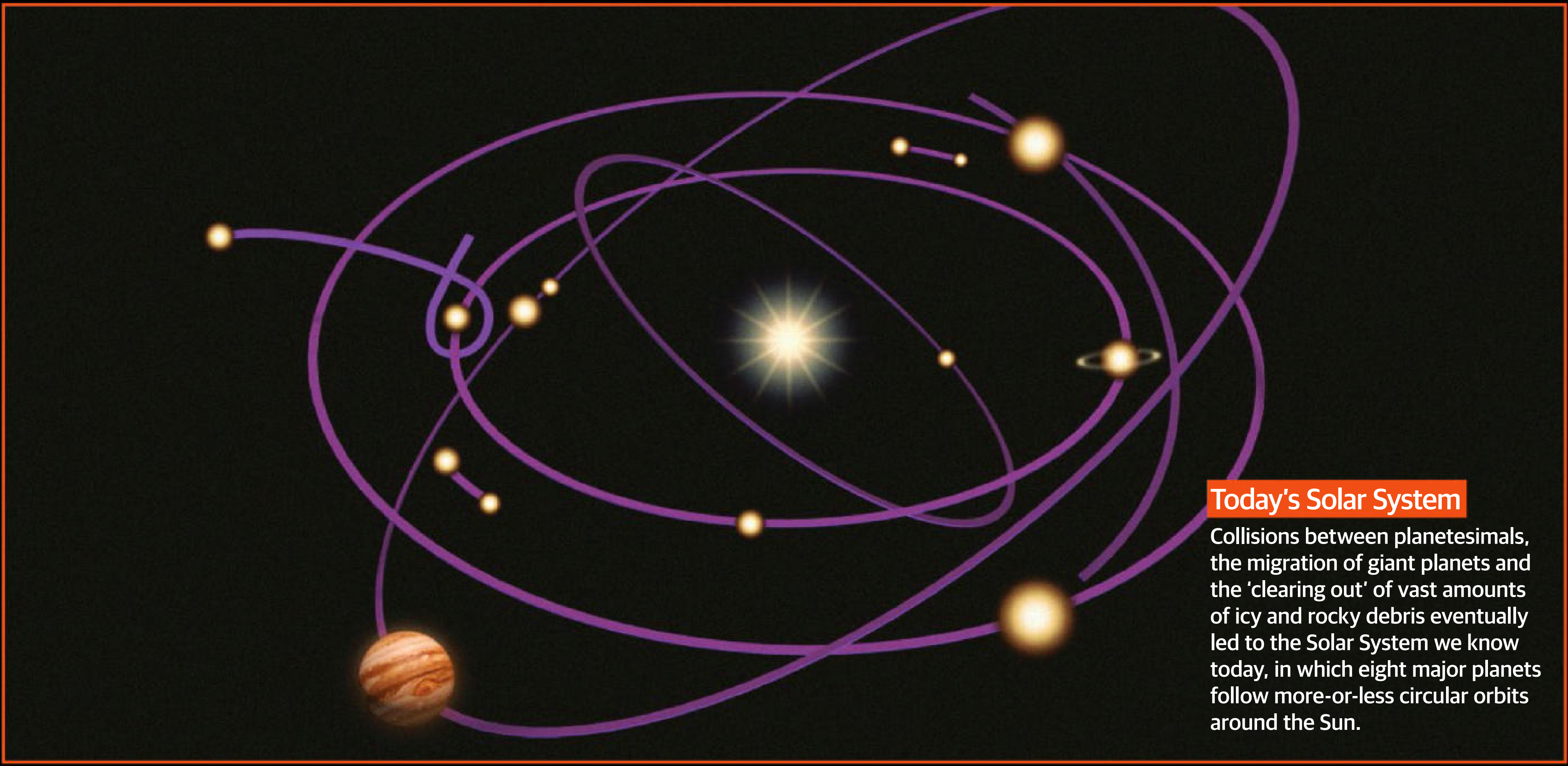
This Mars-sized world is thought to have collided with Earth early on, forming the Moon. One theory says Theia formed in the same orbit as the Earth before being disrupted onto a collision course.

The fifth giant

David Nesvorny's five-planet version of the Nice model calls for an additional ice giant to have formed outside the orbit of Saturn before eventually being ejected from the Solar System.

Planet Nine

'Clustering' in the orbits of distant objects beyond Neptune might be caused by the gravity of a distant protoplanet.

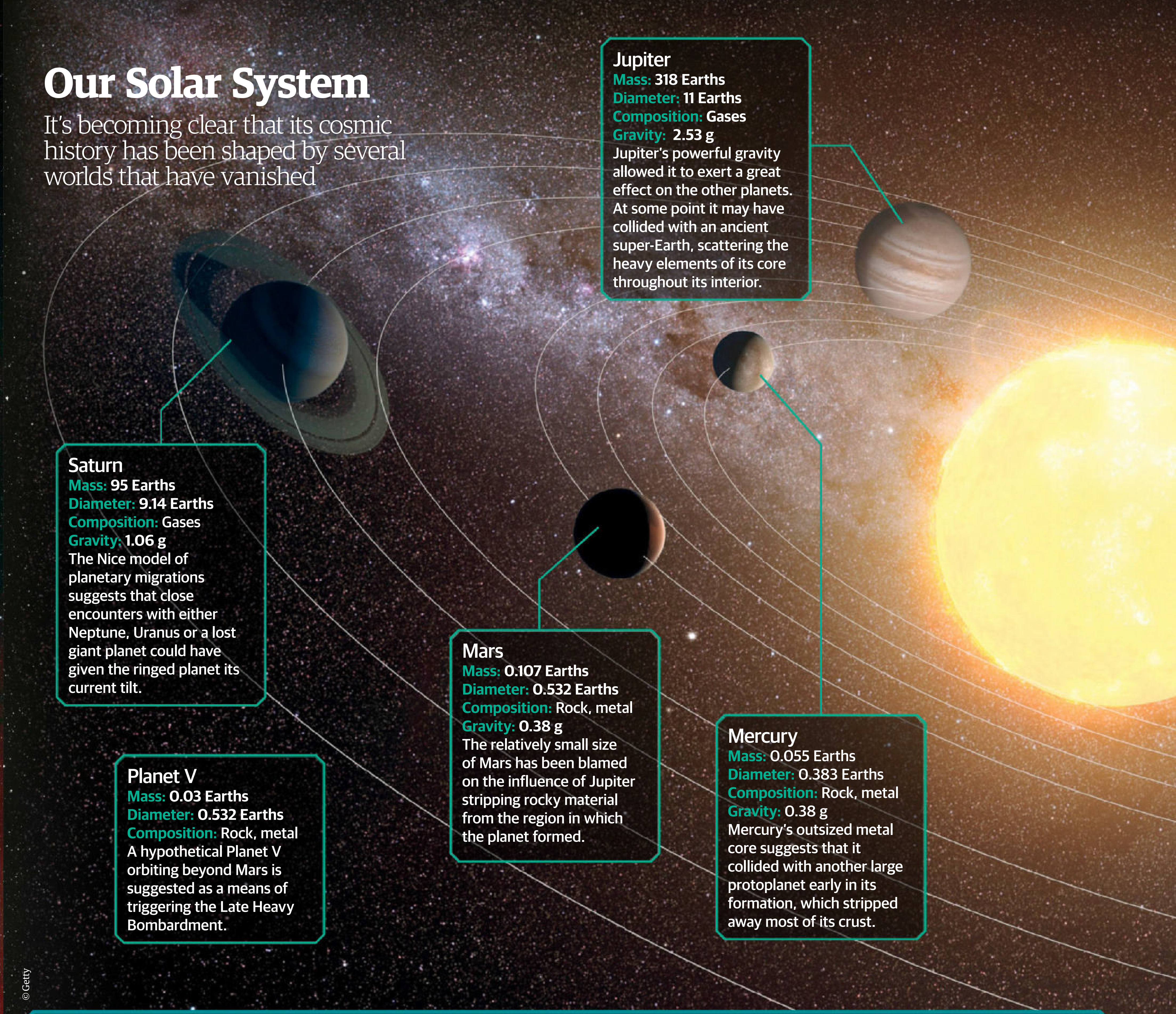


Today's Solar System

Collisions between planetesimals, the migration of giant planets and the 'clearing out' of vast amounts of icy and rocky debris eventually led to the Solar System we know today, in which eight major planets follow more-or-less circular orbits around the Sun.

Our Solar System

It's becoming clear that its cosmic history has been shaped by several worlds that have vanished



Jupiter
Mass: 318 Earths
Diameter: 11 Earths
Composition: Gases
Gravity: 2.53 g
Jupiter's powerful gravity allowed it to exert a great effect on the other planets. At some point it may have collided with an ancient super-Earth, scattering the heavy elements of its core throughout its interior.

Saturn
Mass: 95 Earths
Diameter: 9.14 Earths
Composition: Gases
Gravity: 1.06 g
The Nice model of planetary migrations suggests that close encounters with either Neptune, Uranus or a lost giant planet could have given the ringed planet its current tilt.

Mars
Mass: 0.107 Earths
Diameter: 0.532 Earths
Composition: Rock, metal
Gravity: 0.38 g
The relatively small size of Mars has been blamed on the influence of Jupiter stripping rocky material from the region in which the planet formed.

Planet V
Mass: 0.03 Earths
Diameter: 0.532 Earths
Composition: Rock, metal
A hypothetical Planet V orbiting beyond Mars is suggested as a means of triggering the Late Heavy Bombardment.

Mercury
Mass: 0.055 Earths
Diameter: 0.383 Earths
Composition: Rock, metal
Gravity: 0.38 g
Mercury's outsized metal core suggests that it collided with another large protoplanet early in its formation, which stripped away most of its crust.

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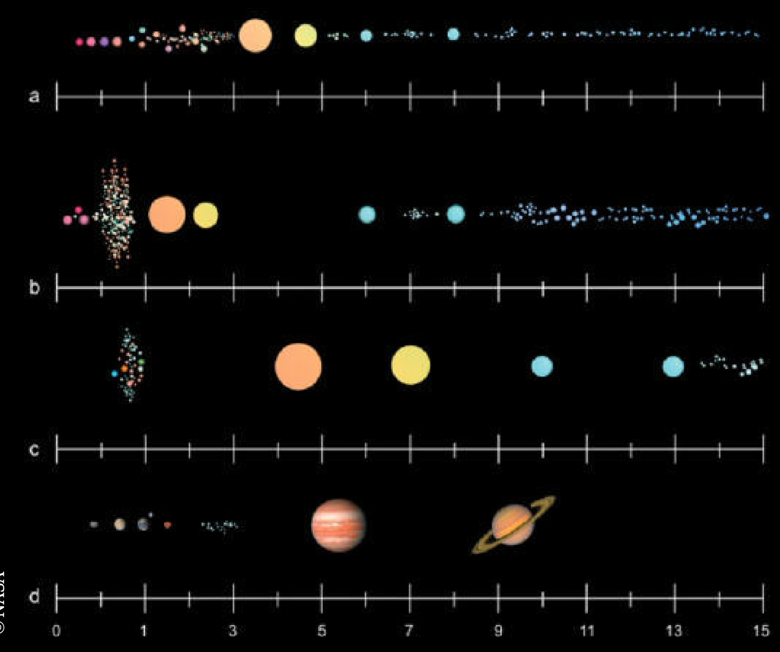
Grand Tack model



© NASA

1 to 2 million years

In the Grand Tack model, the Solar System formed with all four giant planets much closer to the Sun than they are now – inside Saturn's orbit – with a huge number of asteroids and protoplanets, including some far larger than Earth, orbiting inside Jupiter's current orbit.

3 million years

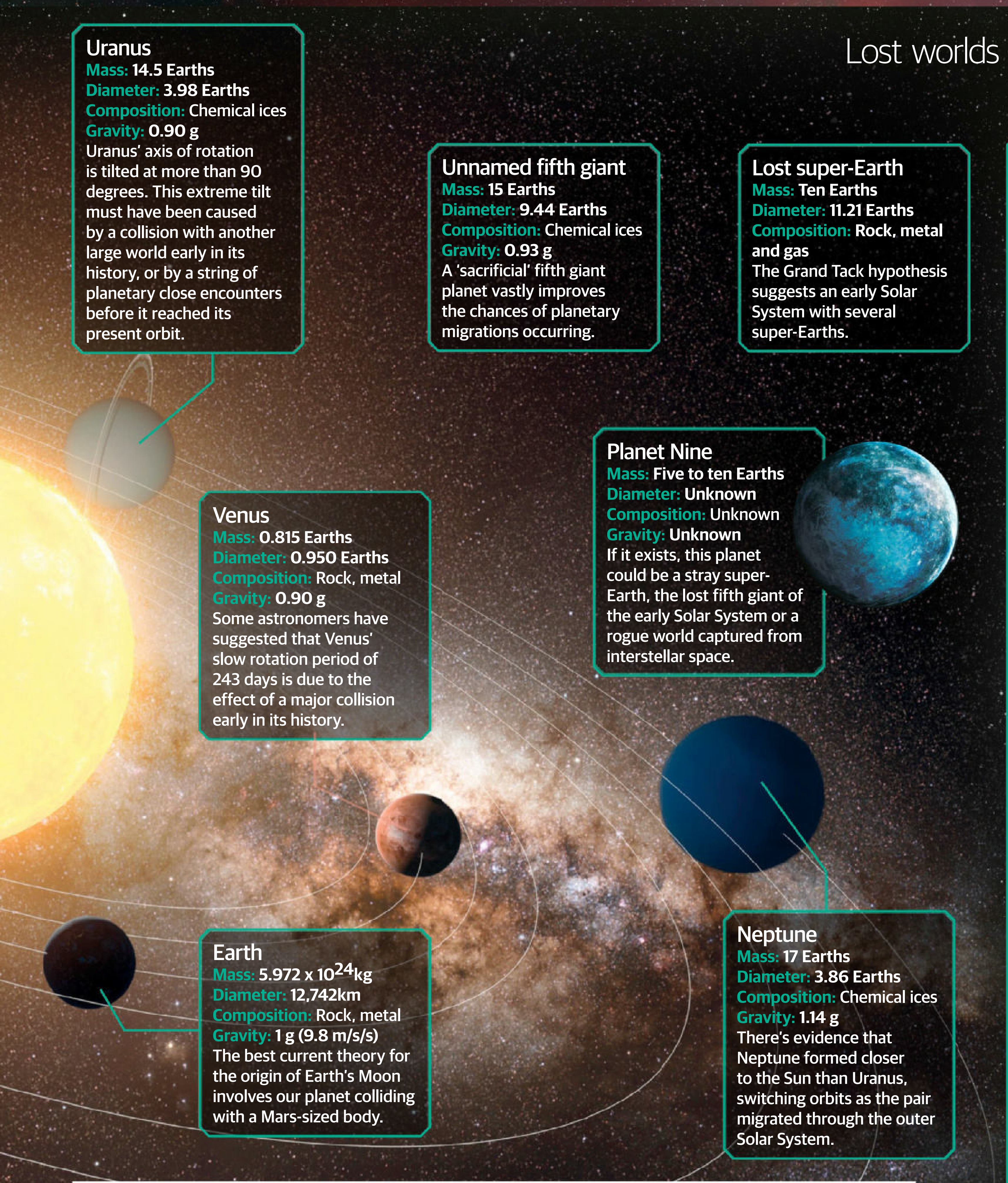
As Jupiter ploughed through gas left in orbit around the Sun, it spiralled in towards the present-day orbit of Mars, with Saturn following. Asteroids and protoplanets in its way were scattered in all directions, with many of them falling into the Sun.

100 million years

Eventually Saturn and Jupiter's orbits locked in a way that caused them to reverse their inward drift, moving out towards their present orbits and eventually disrupting Neptune and Uranus so they too moved outwards.

4.6 billion years

Today the orbits of the giant planets are widely spaced, while those of the inner planets are relatively compact. Only small amounts of rocky debris survive in the asteroid belt, while most of the icy objects of the early Solar System are scattered in the Oort Cloud.



Uranus

Mass: 14.5 Earths
Diameter: 3.98 Earths
Composition: Chemical ices
Gravity: 0.90 g

Uranus' axis of rotation is tilted at more than 90 degrees. This extreme tilt must have been caused by a collision with another large world early in its history, or by a string of planetary close encounters before it reached its present orbit.

Unnamed fifth giant

Mass: 15 Earths
Diameter: 9.44 Earths
Composition: Chemical ices
Gravity: 0.93 g

A 'sacrificial' fifth giant planet vastly improves the chances of planetary migrations occurring.

Lost super-Earth

Mass: Ten Earths
Diameter: 11.21 Earths
Composition: Rock, metal and gas

The Grand Tack hypothesis suggests an early Solar System with several super-Earths.

Planet Nine

Mass: Five to ten Earths
Diameter: Unknown
Composition: Unknown
Gravity: Unknown

If it exists, this planet could be a stray super-Earth, the lost fifth giant of the early Solar System or a rogue world captured from interstellar space.

Venus

Mass: 0.815 Earths
Diameter: 0.950 Earths
Composition: Rock, metal
Gravity: 0.90 g

Some astronomers have suggested that Venus' slow rotation period of 243 days is due to the effect of a major collision early in its history.

Earth

Mass: 5.972 x 10^{24}kg
Diameter: 12,742km
Composition: Rock, metal
Gravity: 1 g (9.8 m/s/s)

The best current theory for the origin of Earth's Moon involves our planet colliding with a Mars-sized body.

Neptune

Mass: 17 Earths
Diameter: 3.86 Earths
Composition: Chemical ices
Gravity: 1.14 g

There's evidence that Neptune formed closer to the Sun than Uranus, switching orbits as the pair migrated through the outer Solar System.

of Mars, which according to many simulations should have grown into another Earth-sized rocky world. It may also explain the lack of atmospheres around Jupiter's giant moons, stripped away when they got too close to the Sun. However, the idea remains far from proven.

Even more intriguing are the theories that conjure up entire ancient planets in order to explain Solar System puzzles. David Nesvorny was one of the first to propose such a missing world when in 2011 he published a paper on the so-called 'five-planet Nice model'. "My initial motivation was to confirm some previous studies of the Nice model that suggested Neptune's migration is not the whole story," explains Nesvorny. "The largest planet in the Solar System, Jupiter, has a slightly elongated orbit, and that's not something one expects from migration. The studies suggested that Jupiter had a gravitational encounter with Uranus or Neptune, and that's why its orbit became elongated."

However, when Nesvorny used mathematical models to run multiple simulations of how such an event could have occurred, he soon hit a problem. "I realised that Uranus and Neptune are often, in fact, way too often, ejected from the Solar System if an encounter happens. I thought that maybe, just maybe, the planet responsible for the elongated orbit of Jupiter is not Uranus or Neptune, but a third ice giant that was sent away."

After running thousands of simulations with slightly different starting conditions, Nesvorny found that systems beginning with five giant planets - adding a third additional ice giant similar to Uranus and Neptune - were up to ten-times more likely to produce the current configuration of four outer worlds than those that attempted to manage with four planets throughout.

Despite this, there are considerable questions about the nature and timing of events in a five-planet system. In order to produce all the

Missions with the evidence

Juno

Launch date: 2011
Operator: NASA
End date: 2021

Juno orbits the gas giant every 53 days on an elliptical orbit that ranges between 8.1 million and just 4,200 kilometres (5 million to 2,610 miles) of Jupiter, dipping lowest as it passes over the planet's poles. The unique gravity maps it has supplied show that Jupiter's core is 'fuzzy' - evidence for a cataclysmic collision in the planet's youth.

© NASA/JPL-Caltech

Hubble Space Telescope

Launch date: 1990
Operator: NASA
End date: Unknown

The Hubble Space Telescope discovered the first objects in the Kuiper Belt other than Pluto. This band of icy worlds that surround our Solar System follow a variety of orbits with different characteristics - astronomers believe that many originated closer to the Sun in the region now inhabited by the giant planets. Their characteristics are key evidence for tracing the influence of lost and roaming planets in the early Solar System, and may even reveal the location of the hypothetical Planet Nine.

© Adrian Mann

Jupiter's gravity had strong effects on planetesimals

Shangfei Liu is researching early Jupiter collisions

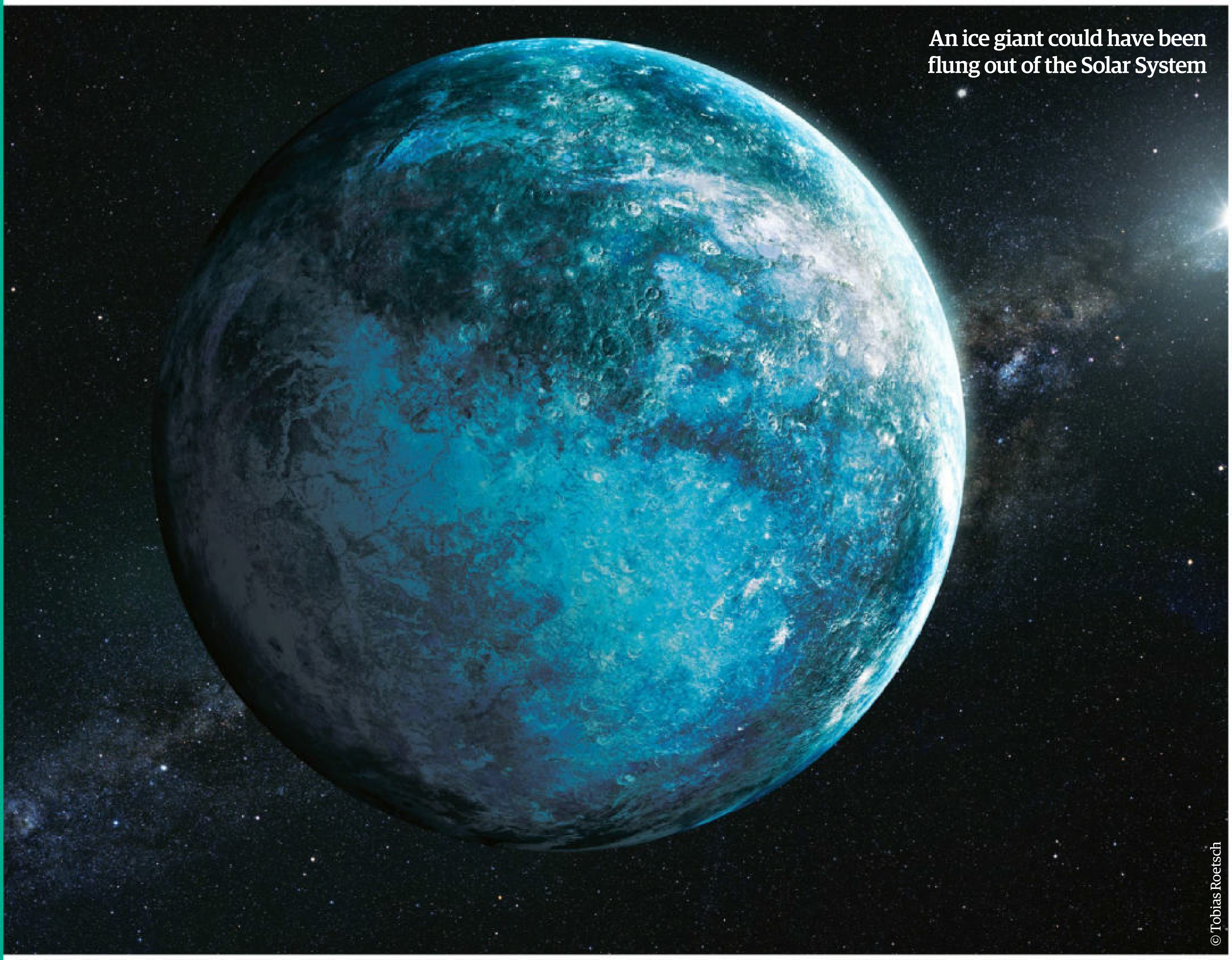
characteristics of the Solar System we have today, any proposed model has to perform a balancing act: the inner Solar System has to remain 'just right' for the formation of its own rocky planets; the icy worlds of the Kuiper Belt must somehow be ejected into their present distinctive orbits, a flattened inner ring surrounded by a 'scattered disc' of objects on more highly tilted and elongated paths; and the smaller comets must be ejected into relatively stable orbits in the Oort Cloud. Most astronomers also hope that planetary migrations can explain the Late Heavy Bombardment, a cataclysmic downpour of asteroids recorded across the inner Solar System about 3.9 billion years ago, half a billion years after the formation of the planets.

Fitting all these jigsaw pieces together is a challenge, but scientists like David Nesvorny continue to find intriguing hints that they're on the right track. In 2015, for example, he realised that a close encounter between the lost giant planet and Neptune could help explain another feature of the Kuiper Belt. "The planet had a gravitational encounter with Neptune, like a spaceship that swings by a planet to change its trajectory. During that encounter Neptune's orbit must have somewhat changed as well, and that little change could have been imprinted into the orbital structure of the Kuiper Belt. There is an interesting concentration of bodies near 45 AU [45-times the distance from Earth to the Sun] known as the 'kernel'. I suggested that the kernel could be explained if Neptune's orbit changed as a result of an encounter, and I performed computer simulations to document it."

One question raised is just what became of Nesvorny's fifth planet after its ejection from the outer Solar System. One possibility that instantly springs to mind is the intriguing Planet Nine - a hypothetical world first proposed in 2016 by astronomers Konstantin Batygin and Michael E. Brown based on their study of the orbits of far-flung worlds in the Kuiper Belt. Brown himself has suggested that the proposed planet, with a suggested mass several times that of Earth and a long, elliptical orbit varying between 400- and 800-times further from the Sun than Earth, could be one and the same as the missing fifth giant.

Nesvorny, however, is not so sure: "I believe it must have been ejected completely and has no relation to Planet Nine. This is because it is difficult to stabilise a Neptune-class planet [15- to 20-times the mass of Earth] when it swings by Jupiter. Planet Nine, if real, is most likely a smaller planet, say five Earth masses. There may have been more smaller planets such as this in the early outer Solar System, and one may have been lucky enough to survive."

According to recent research, however, at least one of these early rogue planets met with a far more spectacular end than mere exile. Professor Shangfei Liu of Sun Yat-sen University in Zhuhai, China, has recently published models that point to



An ice giant could have been flung out of the Solar System

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Hidden planets quickfire

Astronomers hunt for clues of worlds that could have existed

Ghostly fragment

If a giant interplanetary collision created the Moon, could debris from the impact survive elsewhere? Astronomers have suggested that the strange nearby asteroid 2002 AA29 might be such a remnant.

A second Moon

According to a 2011 study, the 'Big Splash' that created Earth's Moon also produced a second satellite that eventually crashed into the larger Moon's far side.

Mars impactor

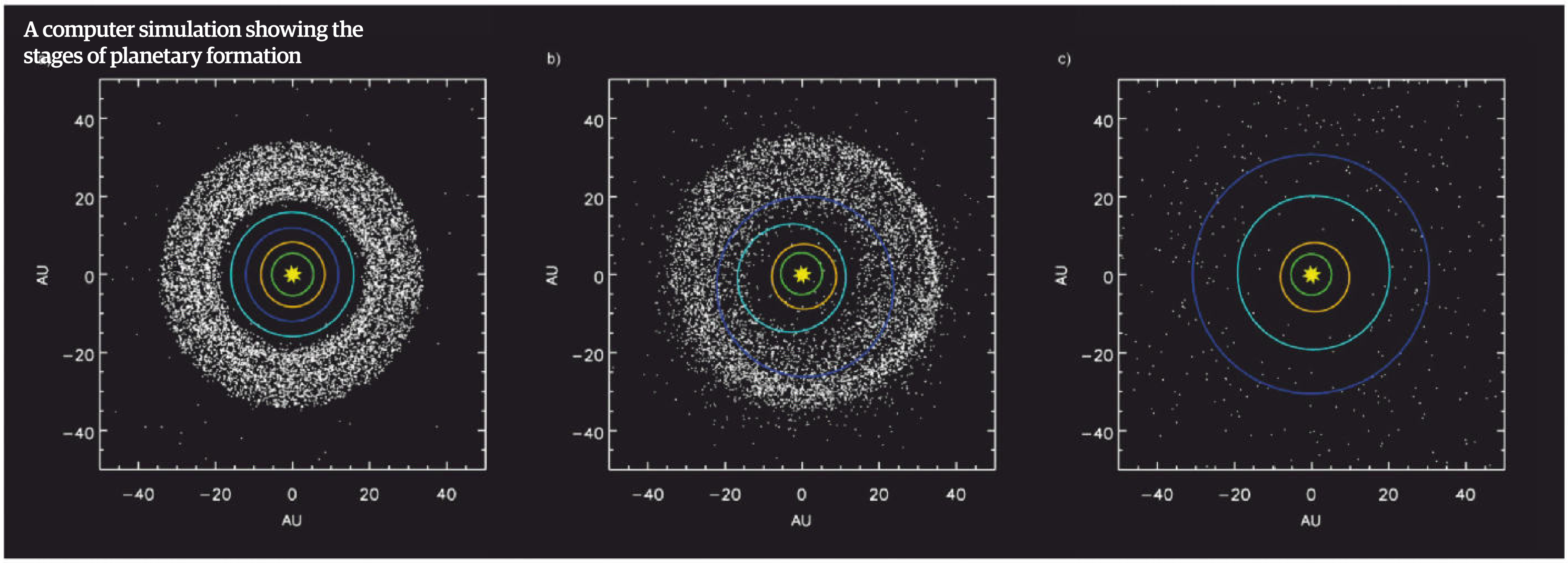
Some astronomers think that an impact from a smaller rogue planet could have formed the vast, flat plain that covers most of the northern hemisphere of Mars.

Lonely wanderers

According to some estimates there could be as many wandering planets, lost in interstellar space after being ejected from their solar systems, as there are in stable orbits around stars.

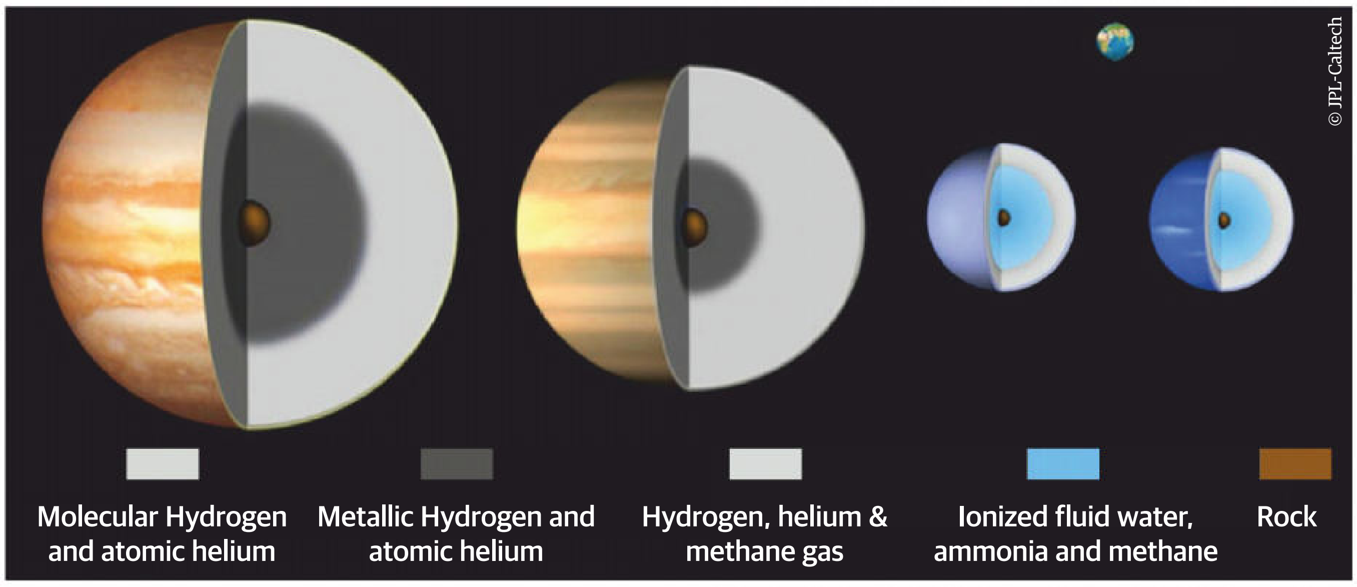
On the hunt

Astronomers have narrowed the search for the hypothetical Planet Nine to a small region of the sky near Orion, and are currently in the middle of a five-year search.



A computer simulation showing the stages of planetary formation

Juno has found evidence pointing to an ancient collision



Molecular Hydrogen and atomic helium
Metallic Hydrogen and atomic helium
Hydrogen, helium & methane gas
Ionized fluid water, ammonia and methane
Rock

© JPL-Caltech

> "I realised that Uranus and Neptune are often ejected from the Solar System if an encounter happens" **David Nesvorny**

a cataclysmic collision between a large 'planetary embryo' and the newborn planet Jupiter early in the history of the Solar System.

The evidence for Liu's theory comes from new discoveries about the giant planet's deep interior. NASA's Juno spacecraft, which has been in a looping elliptical orbit over Jupiter's poles for a little over three years, has given astronomers a unique insight into the planet's internal structure, suggesting that the core region, rather than being a solid ball of rock and metal hidden beneath vast amounts of lightweight hydrogen and helium gas, is in fact diffuse, or fuzzy, with tens of Earth masses' worth of heavier elements spread across about half of Jupiter's radius.

Jupiter's strange internal structure presents a challenge to the most likely theory of how the giant planets formed, as Professor Liu explains: "In the standard picture of gas giant formation, Jupiter began as a rocky and/or icy planetary embryo and later gathered its massive hydrogen and helium gas envelope from the solar nebula."

The result should be a concentrated mass, perhaps up to twice the diameter of Earth, surrounded by layers of low-density liquid and gaseous hydrogen and helium - very different from the structure recently revealed by Juno. "When I first saw the results of such a large, diluted core of Jupiter, I realised that something unusual must have happened to Jupiter in the past," continues Liu.

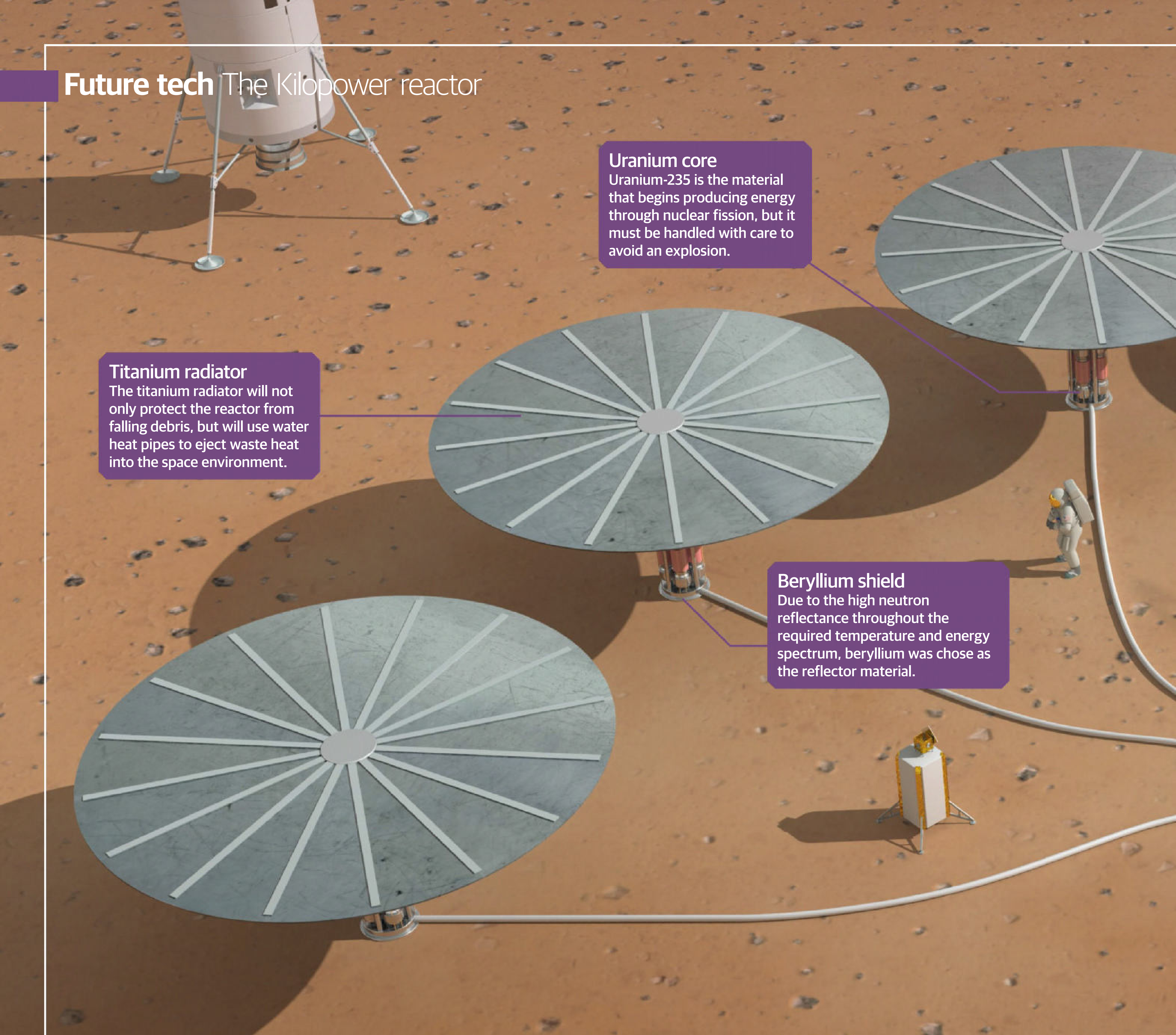
In order to explain the unusual data, Liu and his international colleagues looked more closely at the environment in which the young Jupiter would have formed. They found the rapidly forming giant planet would have played havoc with the orbits of nearby planetary embryos or 'planetesimals' forming in the early Solar System. The team found a 40 per cent chance that Jupiter would suffer a collision from such a body in the first few million years of its life. A similar collision involving Earth itself is famously the best current explanation for the formation of our planet's giant Moon, while another is widely assumed to have knocked Uranus off its axis, producing its present-day tilt and extreme seasons.

In this case, however, disrupting the interior of Jupiter would require a very special collision. The approaching 'impactor' object would have to be very large, about ten-times the mass of the Earth, and it would have to strike Jupiter head-on. Fortunately for the theory, that's not as unlikely as it sounds. "Because Jupiter's gravitational focusing effects are very strong, head-on collisions [occur] more often than grazing ones," explains Liu.

"It sounded very unlikely to me, like a one-in-a-trillion probability," recalls Professor Andrea Isella of Rice University, Texas, a co-author of the research. "But Shangfei convinced me, by sheer calculation, that this was not so improbable. Because it's dense and it comes in with a lot of energy, the impactor would be like a bullet that goes through the atmosphere and hits the core head-on. Before impact you have a very dense core, surrounded by atmosphere. The head-on impact spreads things out, diluting the core."

Importantly, the computer models suggest that once an impact takes place, the effects can be long lasting: "It could still take many, many billions of years for the heavy material to settle back down into a dense core under the circumstances suggested by the paper," points out Isella.

Across the Solar System, it seems, astronomers are finding more and more traces of our Solar System's eventful past and intriguing lost worlds. It remains to be seen whether the searches currently underway for the hypothetical Planet Nine will bring one of these worlds back into the light.



Uranium core
Uranium-235 is the material that begins producing energy through nuclear fission, but it must be handled with care to avoid an explosion.

Titanium radiator
The titanium radiator will not only protect the reactor from falling debris, but will use water heat pipes to eject waste heat into the space environment.

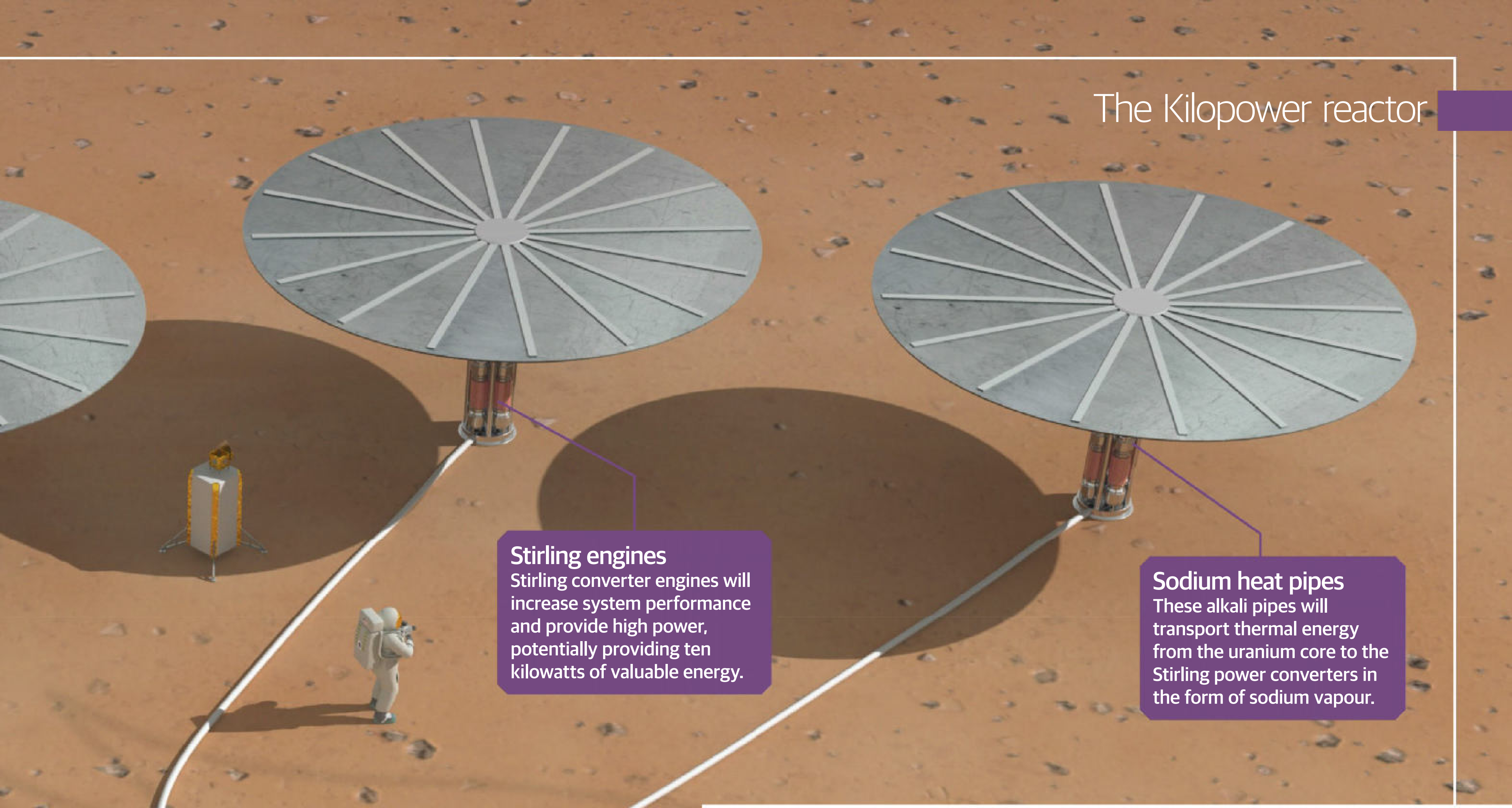
Beryllium shield
Due to the high neutron reflectance throughout the required temperature and energy spectrum, beryllium was chose as the reflector material.

POWERING FUTURE COLONIES

A space colony needs power, and Kilopower reactors could be the answer to these interplanetary problems

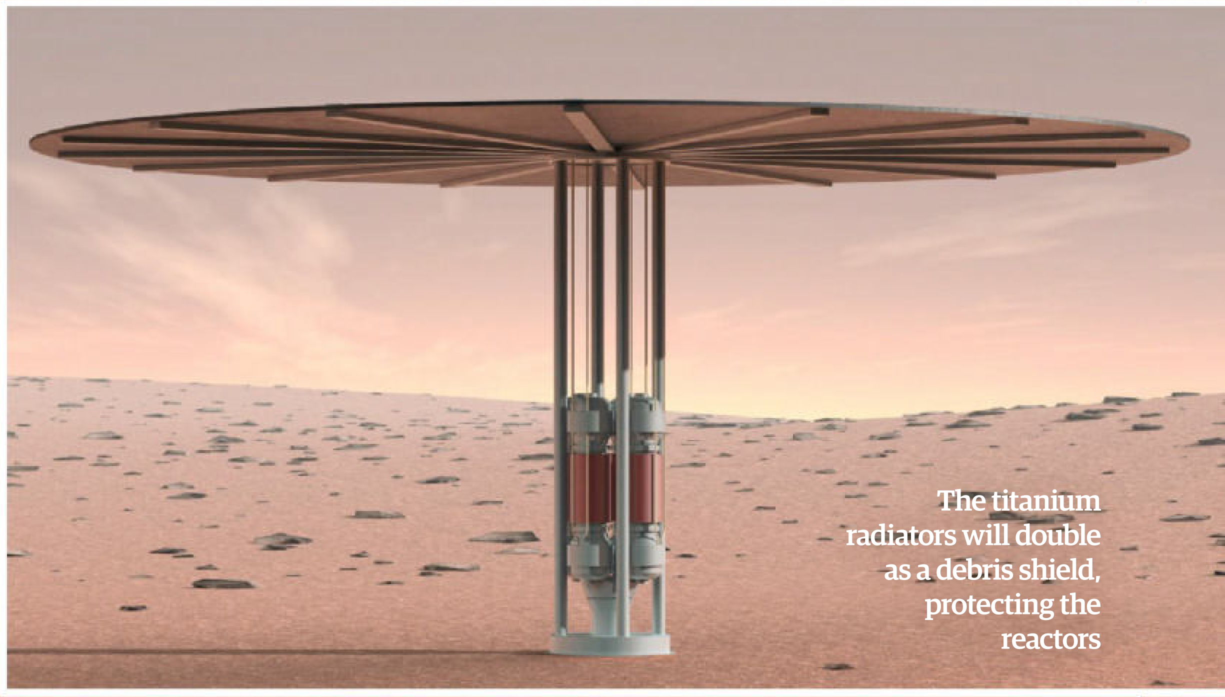
Ambitions to colonise the Moon and Mars require something that can be taken for granted by many on Earth. Here's a hint what it is: we need it for smartphones, televisions, stereos and computers. The answer is, of course, power – electricity to be specific. NASA and the Department of Energy's National Nuclear Security Administration (NNSA) has been developing a small, lightweight power system that can safely and stably generate a suitable amount of power on long-duration crewed missions to the Moon or beyond.

Scientists and engineers at the NNSA's Los Alamos National Laboratory in New Mexico have been working hard on developing a interplanetary power source that can surpass the classic radioisotope thermoelectric generators (RTGs), which convert heat from the splitting of plutonium-238 into electricity. The RTG that powers the Curiosity rover only creates 110 watts of electric power, and will decrease a few percent per year. One issue with colonising Mars, for example, is that crews are going to need much more energy than that in order to purify water, generate



Stirling engines
Stirling converter engines will increase system performance and provide high power, potentially providing ten kilowatts of valuable energy.

Sodium heat pipes
These alkali pipes will transport thermal energy from the uranium core to the Stirling power converters in the form of sodium vapour.



The titanium radiators will double as a debris shield, protecting the reactors

breathable oxygen, power habitats and produce liquid propellant to leave the planet. For these demands, scientists predict around 40 kilowatts (40,000 watts) will be needed.

Kilopower – the name given to this power project – spent a long period of time, specifically between November 2017 and March 2018, testing its prototype power system. This experiment used a solid, cast uranium-235 reactor core and passive sodium heat pipes to transfer heat to its Stirling engines. This test was known as the Kilopower Reactor Using Stirling Technology, or KRUSTY, and can generate at least one kilowatt of power – hence the name Kilopower – but a scaled-up version could generate ten kilowatts of power and operate for roughly 15 years.

This KRUSTY prototype – which some may have gathered is a *Simpsons* reference to its clown character – underwent intense examination which included different phases: being conducted without power to make sure each system worked properly, increased power to heat the core and a 28-hour full-power test to ensure it can undergo reactor start-up, full-power operation and shutdown safely and effectively.

These tests proved extremely successful, and thankfully didn't cause a Chernobyl-style nuclear disaster – which may be fresh in some peoples' minds after HBO's recent series. The next step, outlined by the Kilopower team, is to begin space trials in the next few years. Will the reactor work just as well in zero- or micro-gravity, at the very least remaining stable and safe?

The ultimate goal is to place four scaled-up Kilopower reactors on either the Moon or Mars that can safely generate the power required to sustain the long-duration stay of a crewed mission. Each reactor stands at just 3.4-metres (11-feet) tall, but they are quite heavy, with a ten kilowatt reactor weighing 2,000 kilograms (4,400 pounds). This causes concern in regards to the transportation of the reactors, but only some. In terms of what could be gained, this would be a hurdle scientists at Los Alamos will look to overcome. Until then the Kilopower team will continue to look towards the next series of space experiments.

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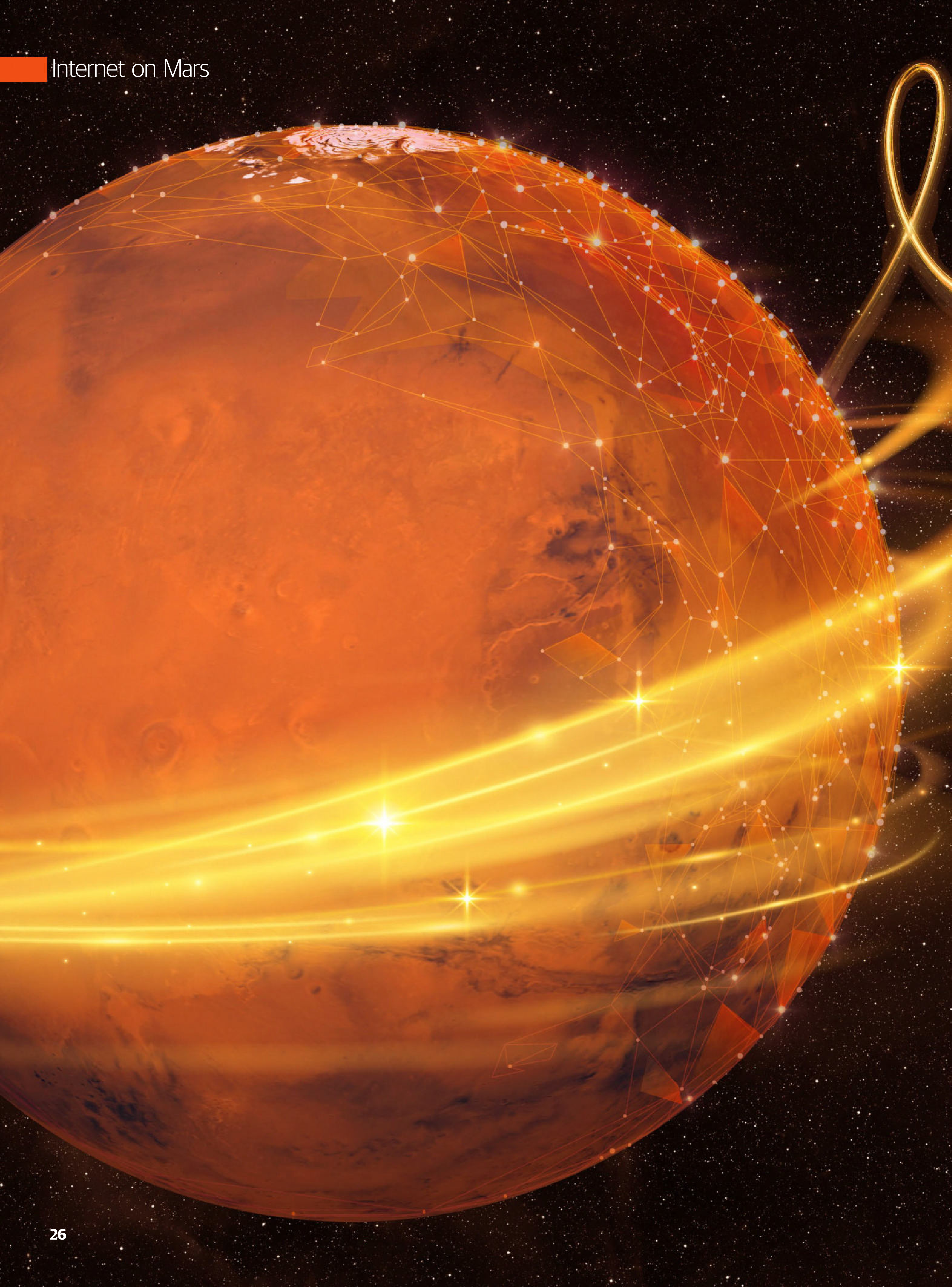
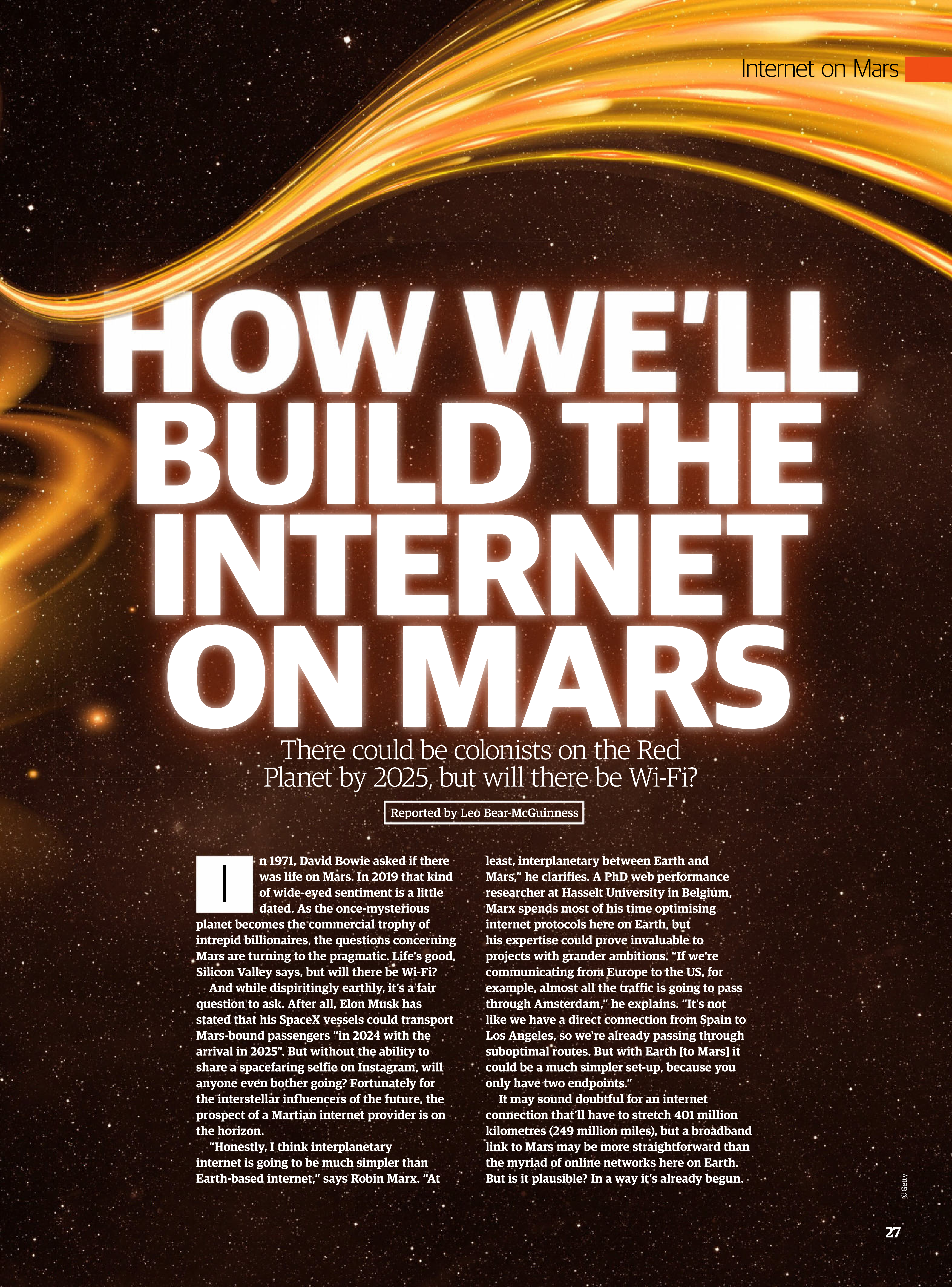




HOW WE'LL BUILD THE INTERNET ON MARS

There could be colonists on the Red Planet by 2025, but will there be Wi-Fi?

Reported by Leo Bear-McGuinness

In 1971, David Bowie asked if there was life on Mars. In 2019 that kind of wide-eyed sentiment is a little dated. As the once-mysterious planet becomes the commercial trophy of intrepid billionaires, the questions concerning Mars are turning to the pragmatic. Life's good, Silicon Valley says, but will there be Wi-Fi?

And while dispiritingly earthly, it's a fair question to ask. After all, Elon Musk has stated that his SpaceX vessels could transport Mars-bound passengers "in 2024 with the arrival in 2025". But without the ability to share a spacefaring selfie on Instagram, will anyone even bother going? Fortunately for the interstellar influencers of the future, the prospect of a Martian internet provider is on the horizon.

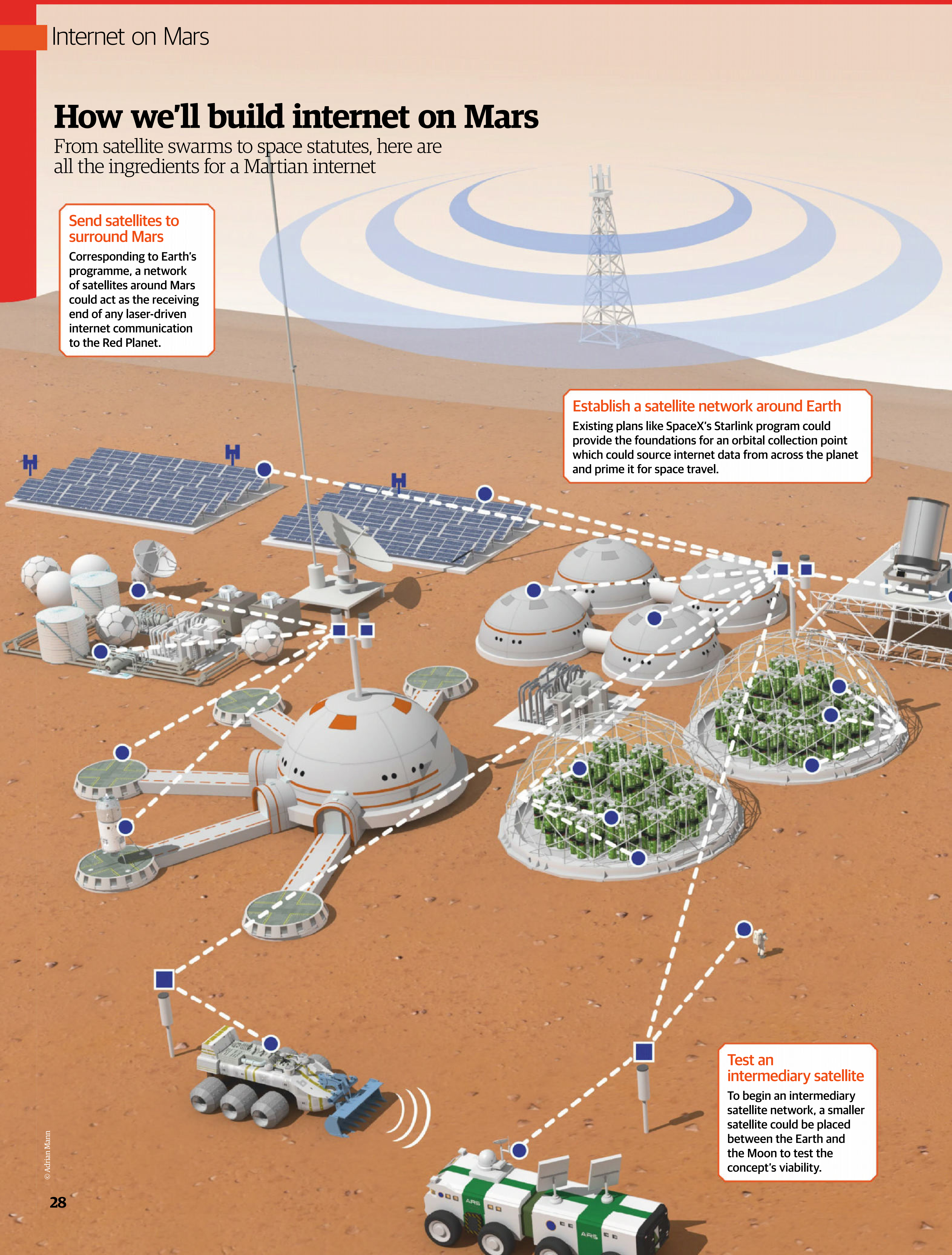
"Honestly, I think interplanetary internet is going to be much simpler than Earth-based internet," says Robin Marx. "At least, interplanetary between Earth and Mars," he clarifies. A PhD web performance researcher at Hasselt University in Belgium, Marx spends most of his time optimising internet protocols here on Earth, but his expertise could prove invaluable to projects with grander ambitions. "If we're communicating from Europe to the US, for example, almost all the traffic is going to pass through Amsterdam," he explains. "It's not like we have a direct connection from Spain to Los Angeles, so we're already passing through suboptimal routes. But with Earth [to Mars] it could be a much simpler set-up, because you only have two endpoints."

It may sound doubtful for an internet connection that'll have to stretch 401 million kilometres (249 million miles), but a broadband link to Mars may be more straightforward than the myriad of online networks here on Earth. But is it plausible? In a way it's already begun.

© Getty

How we'll build internet on Mars

From satellite swarms to space statutes, here are all the ingredients for a Martian internet



Send satellites to surround Mars

Corresponding to Earth's programme, a network of satellites around Mars could act as the receiving end of any laser-driven internet communication to the Red Planet.

Establish a satellite network around Earth

Existing plans like SpaceX's Starlink program could provide the foundations for an orbital collection point which could source internet data from across the planet and prime it for space travel.

Test an intermediary satellite

To begin an intermediary satellite network, a smaller satellite could be placed between the Earth and the Moon to test the concept's viability.

© Adrian Mann

"The first step is going to be something like Starlink," Marx says. "By the time we will have the first preparatory colonies [on Mars], we will have to have planted satellites around the Earth." Starlink, for everyone beginning to lose track of Elon Musk's endless endeavours, is SpaceX's plan to put 11,943 interconnected satellites around the Earth to beam high-speed internet to anywhere across the planet. It's a plan so astronomically ambitious it can only be described as Muskesque. But Starlink's grand potential doesn't just encompass Earth-based internet; given the right direction the satellite network could just as easily send its high-speed internet out into the stars.

But just as a science teacher can't build a tin-can telephone with only one can, humanity can't create interplanetary internet with just one Starlink. To make a connection with the Red Planet, we'll have to send satellites there, too. "The next thing is going to be a similar but much smaller satellite shield around Mars," Marx says.

While this prospect of a Martian satellite network might seem futuristic, the origins of the idea can actually be traced back to 2004 when NASA engineers were hard at work prepping the Mars Telecommunications Orbiter, a $500 million telecommunications relay satellite that would have used high-speed laser beams to relay data from the Mars rovers to Earth each day. Unfortunately the project was cancelled in 2005 so its funds could help reservice the Hubble Space Telescope, but with the right investment from either NASA or

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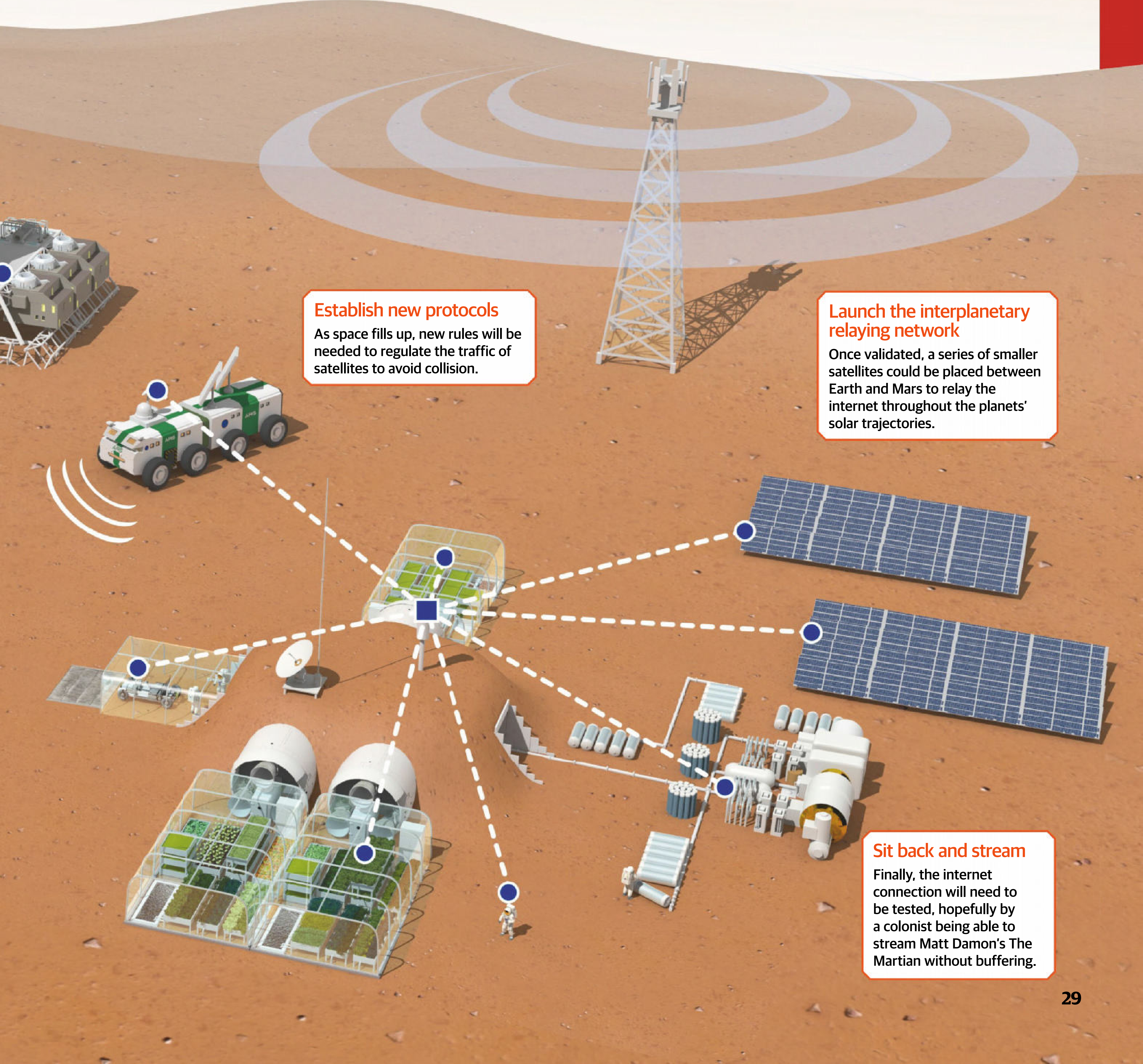
A network of satellites around Mars could receive laser-driven internet communications from Earth



Establish new protocols

As space fills up, new rules will be needed to regulate the traffic of satellites to avoid collision.

Launch the interplanetary relaying network

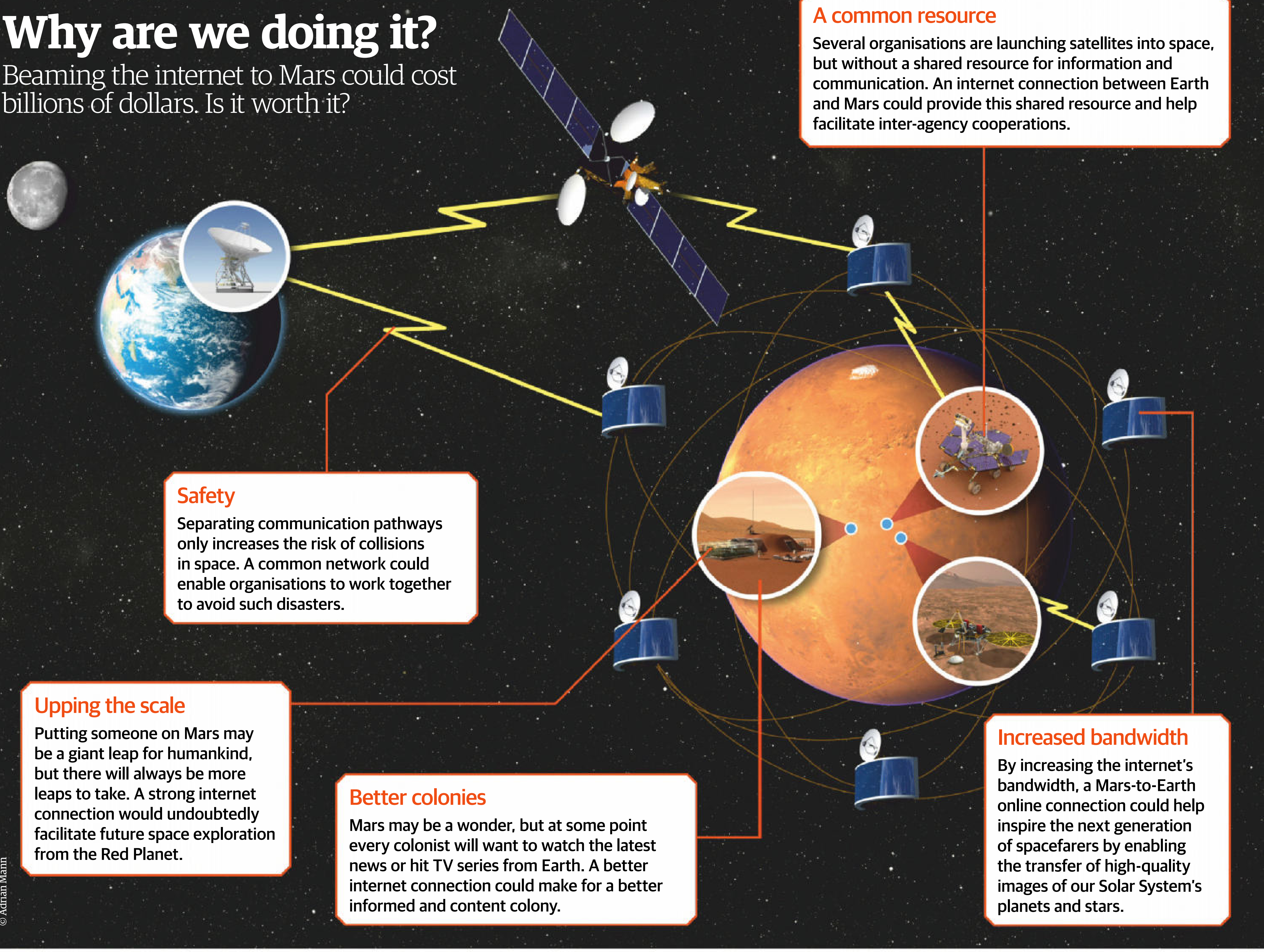
Once validated, a series of smaller satellites could be placed between Earth and Mars to relay the internet throughout the planets' solar trajectories.

Sit back and stream

Finally, the internet connection will need to be tested, hopefully by a colonist being able to stream Matt Damon's The Martian without buffering.

Why are we doing it?

Beaming the internet to Mars could cost billions of dollars. Is it worth it?



A common resource

Several organisations are launching satellites into space, but without a shared resource for information and communication. An internet connection between Earth and Mars could provide this shared resource and help facilitate inter-agency cooperations.

Safety

Separating communication pathways only increases the risk of collisions in space. A common network could enable organisations to work together to avoid such disasters.

Upping the scale

Putting someone on Mars may be a giant leap for humankind, but there will always be more leaps to take. A strong internet connection would undoubtedly facilitate future space exploration from the Red Planet.

Better colonies

Mars may be a wonder, but at some point every colonist will want to watch the latest news or hit TV series from Earth. A better internet connection could make for a better informed and content colony.

Increased bandwidth

By increasing the internet's bandwidth, a Mars-to-Earth online connection could help inspire the next generation of spacefarers by enabling the transfer of high-quality images of our Solar System's planets and stars.

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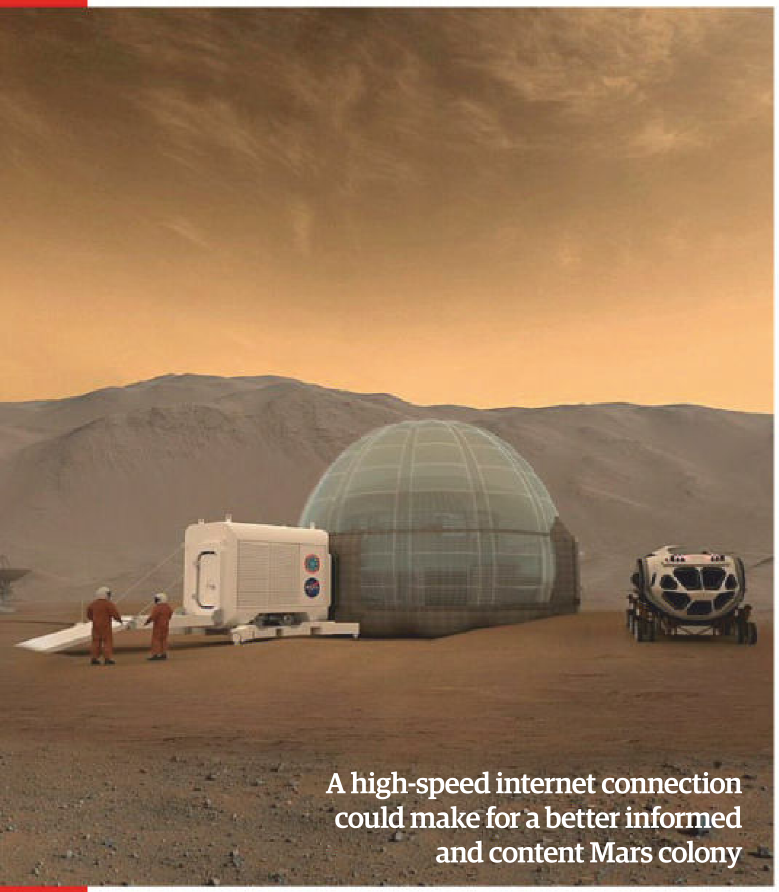


A high-speed internet connection could make for a better informed and content Mars colony

© NASA

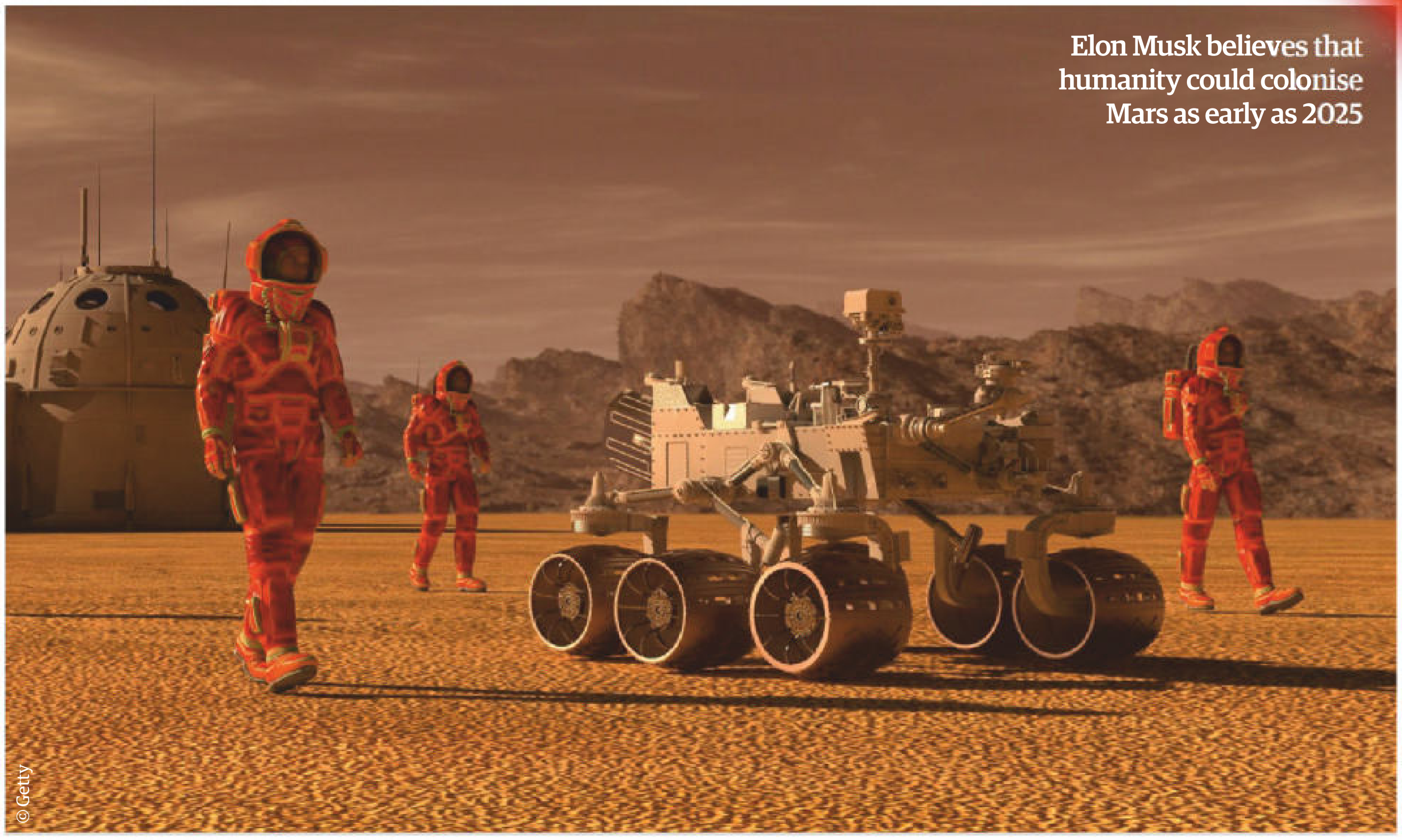
companies like SpaceX, this deactivated data dream could become a reality.

"Then we can start attaching that to the Earth satellites," Marx continues. "We're going to have to introduce intermediate satellites between the planets that can store and forward data." Here's where things get tricky, because while it can be hard enough to get an internet connection between San Francisco and Siberia, at least the distance between the locations remains the same. But the distance from Earth to Mars varies depending on where each planet is in its own elliptical orbit. When the two are at their closest points they're around 54.6 million kilometres (33.9 million miles) apart, but at their farthest there's a 401-million-kilometre (249-million-mile) gap between them. Engineering enough satellites to straddle these varying distances and still communicate effectively is one of the most daunting challenges interplanetary internet poses. But far from becoming deterred, one Texas-based startup is already on the job.

Founded in 2018, Hypergiant Galactic Systems aims to use artificial intelligence and satellites to create the exact kind of relay network needed to bounce internet signals between Earth and Mars. Its founders are already planning to launch their first satellite late next year, straight into the Lagrange point between the Earth and the Moon, where gravitational forces are ideally balanced to park an object. Tests will later confirm whether it can send and receive large amounts of data, and if all goes well a second launch is planned for mid-2021 before further launches on an ongoing basis.

Communicating in harmony with Earth- and Mars-orbiting satellites, Hypergiant's space-age telephone poles could help bring the sci-fi idea of Martian internet into reality. But before anyone starts getting excited at the thought of live-tweeting from Mars, it's important to remember that physics still has its limitations.

"Satellite lasers operate at the speed of light," Marx explains, "but even here on Earth the speed of light is just too slow to do instantaneous stuff." Travelling at a whopping 299,792 kilometres (186,282 miles) per second, a speed-of-light internet connection on Earth could hardly be called slow.



Elon Musk believes that humanity could colonise Mars as early as 2025

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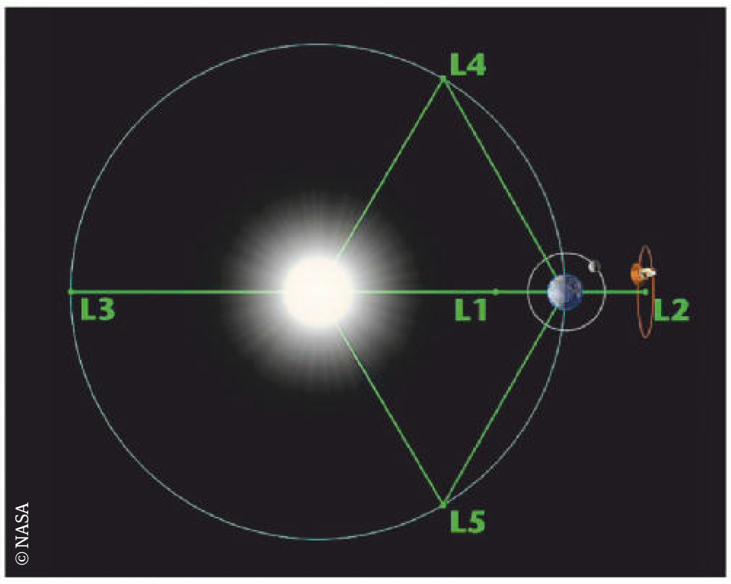

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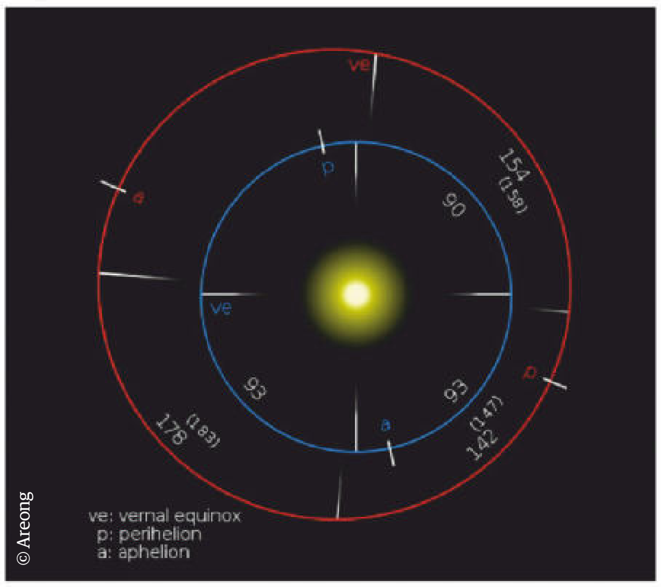
A diagram of the Lagrange points associated with the Sun-Earth system



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A diagram of Mars' and Earth's separate elliptical orbits around the Sun

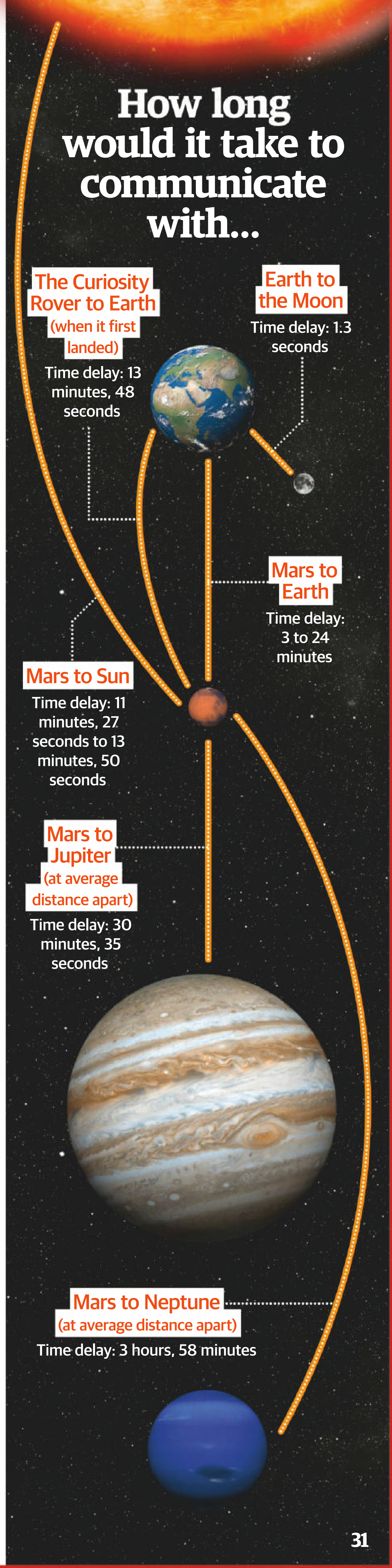
> "Honestly, I think interplanetary internet is going to be much simpler than Earth-based internet" **Robin Marx**

But if on an extended trip to Mars, the Wi-Fi signal might be a little late for any colonist trying to chat over Whatsapp. Yet against the laws of physics, there's not a lot engineers can do. "Remember that internet communications have two different parameters: latency and bandwidth," Marx explains. "The bandwidth is manageable by adding more satellites, but latency is never going to be - it will always be dependent on the time of year and where the planets are."

And the speed of light isn't the only law interplanetary internet could come up against. Thanks to a recent close call between satellites owned by the European Space Agency (ESA) and SpaceX, the laws governing space are being questioned more than ever before. The incident, in which one of the ESA's observation satellites had to use its thrusters to avert a potential collision with a Starlink internet satellite, has since sparked efforts to upgrade the rules of space to better govern a slightly fuller Solar System. And as any high-speed Martian internet service will require fleets of satellites between Earth and the Red Planet, it's looking less likely that any more devices will be jumping into space before they're properly approved to be there. For all the technical and scientific challenges interplanetary internet poses, bureaucracy might be its greatest obstacle.

Of course, it shouldn't come as a surprise that setting up a router on Mars would come with so many impediments. But considering the thousands of satellites that will need to be launched, the regulations that will have to be created and the light-speed limitations that will impede its function, the prospect of Martian internet seems so formidable one might understandably wonder if it's even worth the effort. After all, space agencies have been able to send people to the Moon since 1969, but stopped only three years later because it wasn't a cost-effective means of studying its surface. So aside from enabling Martian selfies, why is interplanetary internet worth attempting?

Well, sending people to visit and colonise Mars without the internet may be a bit like putting the cart before the horse, because while the internet is known as a source of frivolous entertainment, its



How long would it take to communicate with...

The Curiosity Rover to Earth (when it first landed)
Time delay: 13 minutes, 48 seconds

Earth to the Moon
Time delay: 1.3 seconds

Mars to Earth
Time delay: 3 to 24 minutes

Mars to Sun
Time delay: 11 minutes, 27 seconds to 13 minutes, 50 seconds

Mars to Jupiter (at average distance apart)
Time delay: 30 minutes, 35 seconds

Mars to Neptune (at average distance apart)
Time delay: 3 hours, 58 minutes

> “If we're really serious about building an interplanetary civilisation, we're going to need ways to communicate” **Robin Marx**

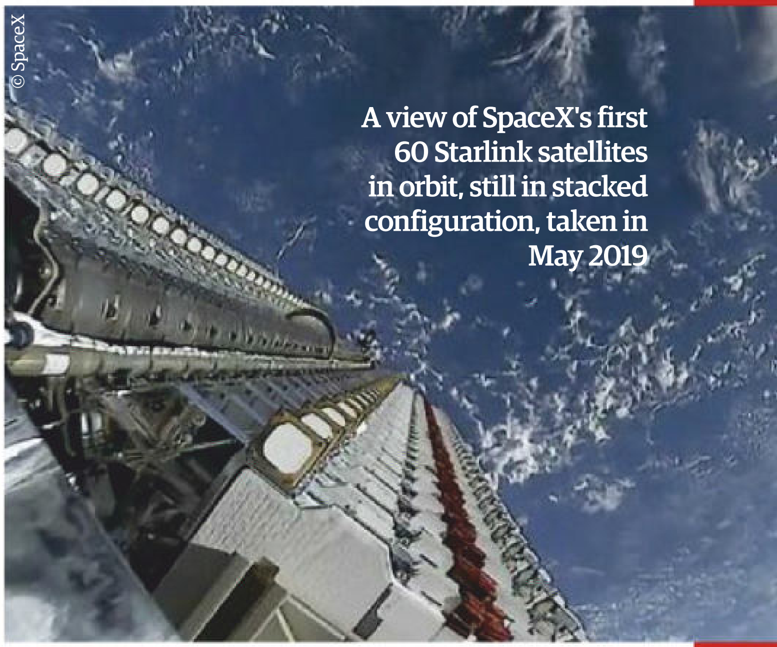
practical capabilities for communication could be crucial for the spaceflights of the future. As the ESA-SpaceX satellite incident perfectly demonstrates, a little communication can go a long way to averting disaster. And if such organisations continue to pepper their spacecraft around the Earth without consulting one another, it'll only be a matter of time before these near misses become costly collisions.

Writing prophetically on the reasons to create interplanetary internet in a 2018 paper published in *Aerospace and Electronic Systems*, a team of researchers cite this exact rationale, stating that “both manned and unmanned missions would benefit from sharing resources, as is done currently on the internet, rather than multiplying parallel incompatible networks”.

Acknowledging the inspirational aspects of space travel, the authors from the Hong Kong University of Science and Technology and University of Helsinki also claim that by increasing the current internet's bandwidth, a Mars-to-Earth online connection could help transmit high-quality images of our Solar System's planets and stars, which could help inspire the next generation of spacefarers. And as the initial exploration of Mars turns into further space colonisation, the researchers note that this will “require increasing communication resources. Therefore, it makes more sense to progressively scale up the [internet] network than deploying all the resources for future missions at once.”

“If we're really serious about building an interplanetary civilisation, we're going to need ways to communicate between the planets outside of the official NASA or ESA communication channels,” Marx agrees. “Just like on Earth, we'd want the internet to be a commodity for everyone.”

So, ironically, interplanetary internet wouldn't be that revolutionary at all. Just like the terrestrial internet we know today, it could enable multiple organisations to create, communicate and collaborate with each other on a host of projects. The only difference being that, unlike Earth's internet, the online world of outer space would exist initially for just one goal: to facilitate the new age of space exploration - to settle humanity in the stars. And no matter the cost, the number of satellites needed or the sheer level of technical skill required, it's indisputable that any tool that could help achieve that species-defining goal should at least be attempted.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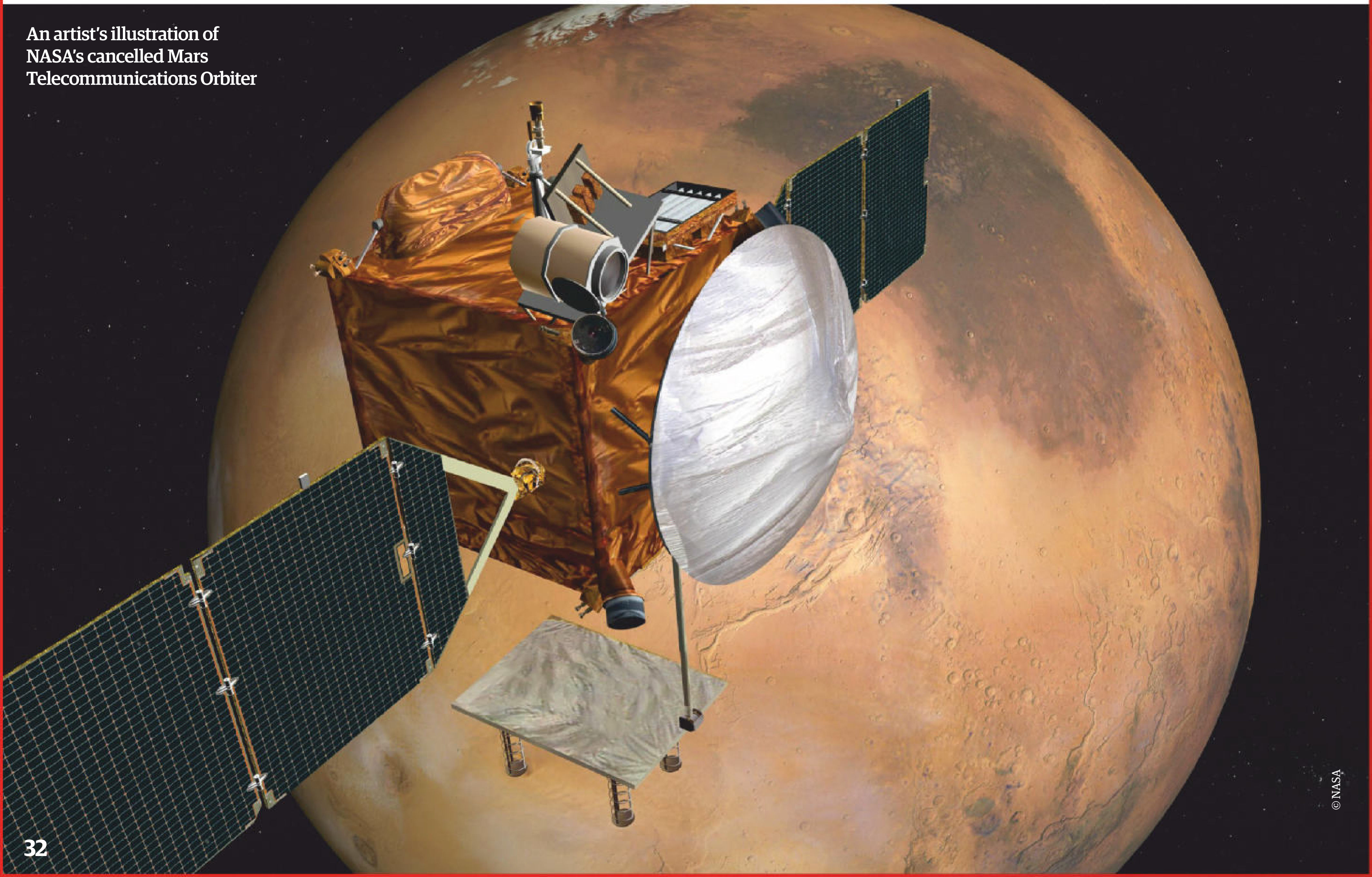
A view of SpaceX's first 60 Starlink satellites in orbit, still in stacked configuration, taken in May 2019

Plus, once in the hands of creative colonists with the radical perspective only a fresh world can give, there's no telling what new online wonders Martian internet could birth. Spacebook? Sputnify? Delivermoon? Or countless streams of Martian memes, videos and original creations? When looking to the internet's future, perhaps we shouldn't be listening to the Silicon Valley CEOs who will build it, but the creatives who will fill it.

“I don't think we've even seen the tip of the iceberg,” David Bowie famously said during a characteristically prescient interview in 1999. “I think the potential of what the internet is going to do to society, both good and bad, is unimaginable. We're actually on the cusp of something exhilarating and terrifying.” In many ways, nothing's changed. Will there be Wi-Fi on Mars? Only if we dare.


An artist's illustration of NASA's cancelled Mars Telecommunications Orbiter

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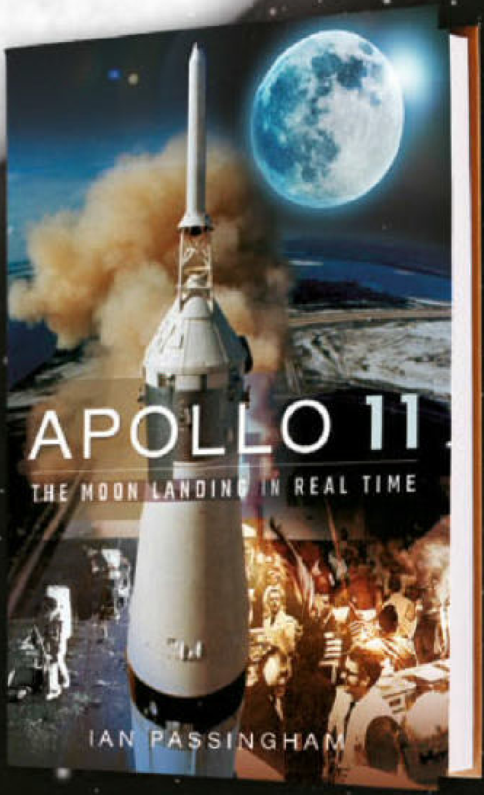

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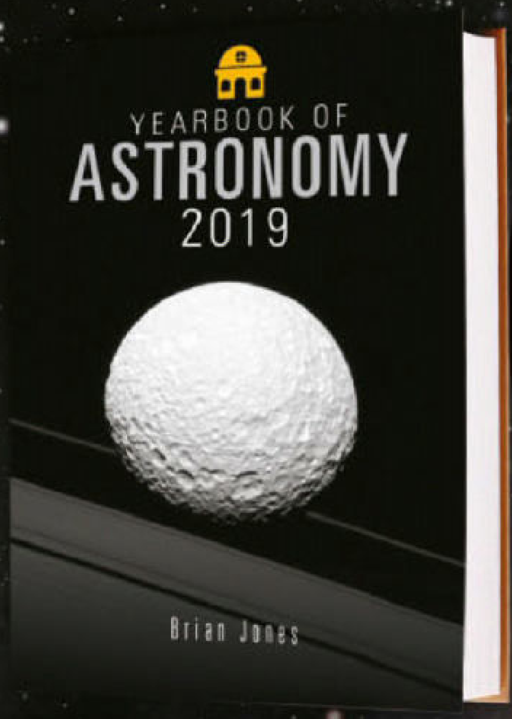

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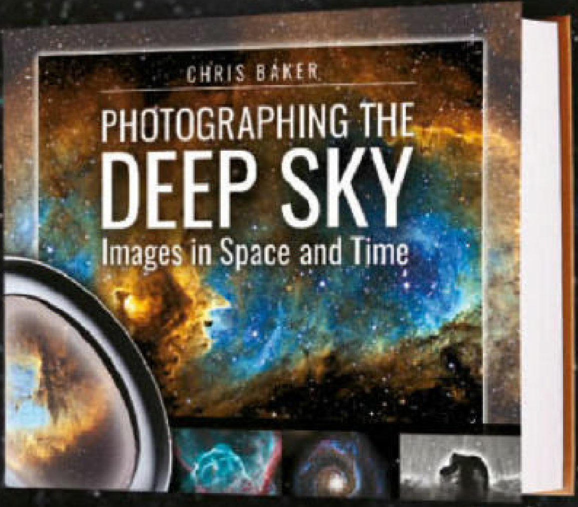

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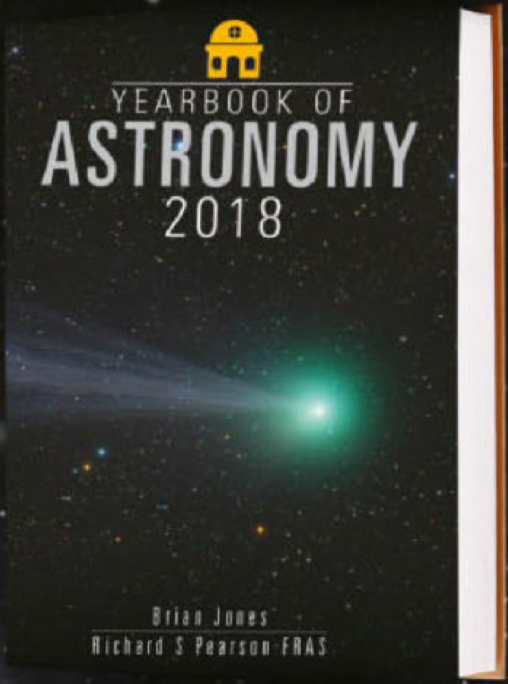

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INTERVIEW BIO

Tiffany Francis

A nature writer from South Downs, Hampshire, UK, her new book *Dark Skies: A Journey into the Wild Night* describes a year-long story of her travels around the United Kingdom and Europe exploring the nighttime landscapes and what influence they have, both now and in the past.

From seeing the polar nights and northern lights in Norway to celebrating an ancient Celtic astronomical festival at South Downs, these experiences have shaped people for thousands of years, and Tiffany has delved into the culture of astronomy.

HUMANITY'S CONNECTION WITH THE NIGHT SKY

All About Space speaks to Tiffany Francis about her adventures all over the United Kingdom and Europe in a pursuit to understand astronomy's profound influence over millennia and how we're losing touch with it

Did you write the book because you believe that people have lost the connection with the night sky?

I didn't actually. That is something that I discovered as I went. But actually the main reason I decided to write it is because one evening in the summer, I looked out and realised that it was a really beautiful evening outside, and I just decided I didn't really want to be in.

I decided to go out for a night walk, and I had this lovely experience just out on my own on our local hilltop, and it kind of spurred on a new hobby in me. I realised how much I enjoyed being out on my own at night and the peace and solitude of it.

That was how I started spending more time out at night, and then the book came from that because I just naturally became really fascinated with it. Why aren't we drawn to the night? But at the same time we feel that the night time is something not to be explored, in a way we're encouraged to stay inside. It was this interesting dichotomy that I was interested to explore.

Your travels took you to Tromsø in Norway. What was it like to spend an entire week in the darkness during the polar night?

It was strange, I'm not going to lie. It was fascinating and I kind of loved it, in a way. But I was quite happy to see sunlight when I got home. It was really interesting because the main reason I went there, it wasn't actually to see the northern lights, it was to see the polar night and talk to people about what it's like to live in darkness all the time, because obviously in the United Kingdom people suffer from seasonal affective disorder, but actually we still have a good, long session of daylight every day, even in midwinter. To go from that to literally nothing at all, I was just fascinated by it and it was very confusing.

I was on this research trip and I wasn't going to set an alarm, I was just going to go with the flow of each day, so I woke up at random times, because there was no light to wake me. Some mornings I would wake up really early and some I would wake up just before lunch and think, 'Oh. I really need to go out and do stuff.'

It was quite confusing, and after a while I did become a little disoriented, but I still enjoyed it. The really fascinating thing was in these sort of Scandinavian countries where they have to deal with this kind of difference in light and darkness, they seem to embrace it. It was very cosy and they embraced the cosiness of it all. Lots of fairy lights and cake and coffee and all these very typical Scandinavian things, but it really works because you didn't mind that it was dark all the time.

Does that mean at different times of the year they experience light all the time?

Yes, so in the chapter where I go to Helsinki, Finland, I basically do the opposite - I went to see the 'midnight Sun'. That is literally just the flip side, so then it was light all the time, except from about 01:00 to 03:00, it was like dawn. That was the darkest it got, and then it was light again.

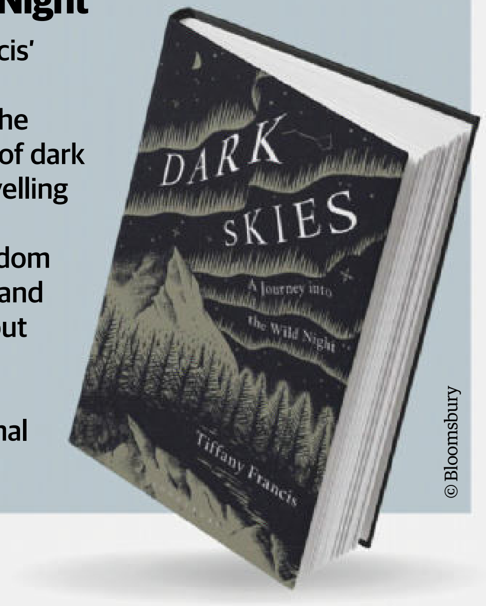
It was really interesting, so I wanted to go to both countries to kind of just look at this crazy contrast of how much light and darkness they're exposed to and how they cope with it and embrace it. And it was really fascinating. I think Finland was even more disorienting than Norway, because in the dark you're just a little bit sleepy and wandering around, but in

Tromsø is ideally located to enjoy city life and the aurorae

© Andi Gentsch

Dark Skies: A Journey into the Wild Night

Tiffany Francis' latest book reflects on the importance of dark skies by travelling around the United Kingdom and Europe and learning about humanity's connection with nocturnal landscapes.



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The Milky Way can be seen from International Dark Sky Reserves

Below left: Noctilucent clouds are the result of high-altitude clouds reflecting light from a setting Sun

Finland it was just so light, I felt so energetic all the time. But at the back of my mind I was like, 'I should really be asleep.' It was lovely. I loved it.

Do you think that the northern lights have had a more profound effect on civilisations than originally thought?
Yeah, I think so, because they are one of these amazing things people obviously had no scientific way of explaining for thousands of years until modern science cast a light on it.

You can just imagine all these amazing ideas, stories and myths that came out of these crazy lights in the sky and, you know, especially people who may be visiting an area and had never seen them before. They probably thought it was witchcraft or something. I love to think about that and imagine what kind of reason people thought these lights were there, whether it was a sign from God or whether they were just very connected with nature and just saw it as a calmness, this beautiful thing.

Based on your visit, why is it that the Royal Greenwich Observatory is so important to the world of astronomy, and in particular British astronomy?
It goes back to the time when Britain had been one of these many countries that were at the forefront of 'modern science', I guess you'd call it. This enlightened modern science. In Britain we also tend to have these fancy buildings that are like these big, symbolic gestures. I think the observatory is a very beautiful building in this beautiful park. It's high up so everyone can see it. If you were a ship coming into the dock, you could see the little orange time ball on the top. It's just one of these buildings I think is symbolically very powerful, as well as the important actual science that happened inside it.

The building marks this shift in our knowledge and how suddenly we started snowballing with our knowledge about what we discovered about the stars in the sky, obviously with navigation and how important that is. I mean, it's a hugely important part of British history, and that has so much to do with astronomy. I think it's just as important symbolically as it is practically of what science has discovered and how it was a very important part of British identity.

The development of navigation is an important point. Do you think it goes under the radar?
Absolutely! I think people forget about that, especially these days. I mean, I am rubbish at orientation and I couldn't guide my way by the stars. I use Google for everything... I'm a typical millennial. But we forget that everything we learned about mapping the world and everything all relied on astronomy and stars. That's quite sad, thinking how many skills we've lost there.

It's not completely disappeared - plenty of people can still navigate by the stars. It's obviously something that's been superseded by technology,

The Royal Greenwich Observatory was key for not only astronomy, but navigation

© Wiki

An International Dark Sky Reserve is an excellent location to do some observational astronomy

Below: Navigation using the stars helped Portuguese explorers find their way to India

which is very useful, and it's great that everyone can use a navigation app on their phones. But it would be nice if we could rely more on our instinctive basic knowledge than just our phones.

At the Royal Greenwich Observatory you talk about thinking about going into space and holding a meteorite that is as old as the Sun. Do these experiences bring an affinity to space, or is it harder to gain an affinity when you think about the vast timescales and enormous sizes?
Sometimes I feel like we almost know everything and think you can kind of catch all that noise, but actually, when you start looking into it, the vastness of space can actually be very overwhelming and make us feel completely insignificant. I don't actually find that a bad thing. It sounds like I'm being a bit cynical, but I like the idea that no matter how big and important we think our species is and how much we think our problems are really big and all this, when you think about space and the universe, it just puts everything in perspective, which I really like. This is because it makes us realise that we are all just one part of a very, very, very huge universe. I quite like that; I find it very reassuring.

How damaging is light pollution, and what do you think people who live in populated urban areas are missing out on?
Because I live in the South Downs [UK], where I live is actually an International Dark Sky Reserve, so I'm really lucky because it's just really great stargazing. I can sit in my garden and just watch the stars with the naked eye. So I'm very grateful for where I live.

I lived in London for a few months and obviously saw the comparison there is huge, because in London you can see the stars at night, but they're barely visible. To be honest, it's not really a great experience.

Light pollution is something I've learned a lot more about since researching this book, because you think we've got so many environmental problems in the world and there are so many things to think about, and I hadn't really thought about light pollution. But after looking into it, it's extremely important.

There are lots of environmental reasons why light pollution matters, say, for example, wildlife. There's loads of different wildlife that are having their routines completely skewed because of false light and them thinking that electric light is the Moon.

There are lots of actual, practical reasons why light pollution is physically damaging the environment and our ecosystems.

Of course something just as important is how much we do have this connection with the night sky and how important it is to humanity to recognise our place in the universe and to look up at the stars and think about how long we've been here, the age of our planet and all those kind of lovely things. You can't really do that without looking at the stars. It's all very good reading about it in books, but nothing really is quite as deeply penetrating as actually just looking up at the stars, and then being faced with that.

It seems to be one of these issues which is more easily fixed than other environmental problems because it's just the case of where lights are, which way they're facing and the intensity. It gives me hope because I feel like compared to a lot of other environmental issues, it seems to be relatively more simple, but it's just a case of putting action into place today.

What is an International Dark Sky Reserve, and what is it like to visit one?
I don't know what the official requirements are to meet in order to be one, but it's basically, in simple terms, where the light pollution in the area is so low that they're considered really good for stargazing. We've got a handful in the country, and the South Downs is the most recent one to be designated in the UK.

It's just really amazing, because we're so used to everywhere we go, there's at least one street light on, and there's some kind of glow on every horizon pretty much wherever you go. When you go into one of these International Dark Sky Reserves, such as Snowdonia, because Snowdonia is a national park it's not got loads and loads of buildings or houses and it's very wild. You can literally be in the middle of a landscape and really not see any light at all. And then you look up and because there's no light pollution reflecting off the sky either, the whole sky is just this beautiful, dark mass with beautiful stars smeared all over it. You know when you have a picture on your computer and you up the contrast and all the dark goes darker and all the white goes whiter? That's what it's like to go to an International Dark Sky Reserve.

Where was the best place you went to observe the night sky?
Oh, that's a good question. I mean, it's a bit of a cheat because you can only really see it in certain places, but nothing beats going and seeing the northern lights. Even from Tromsø, which is a city, it was just very dark. It was just this beautiful, dark place, even without the northern lights there. I was out there even before the northern lights started showing and the stars already looked beautiful. When the lights starting showing, I had never seen anything like it.

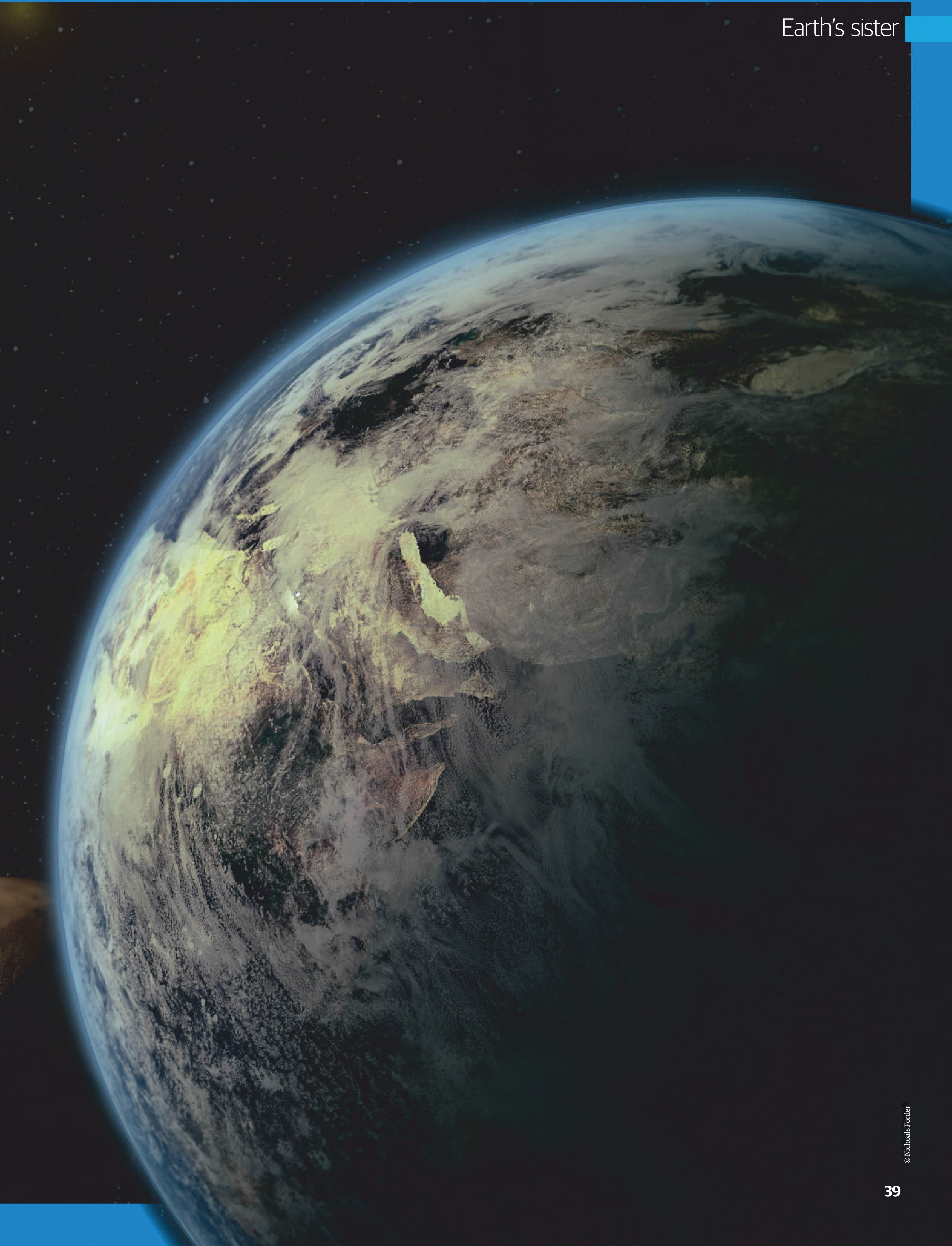
But I will say actually, in July this year I also went to Kielder Observatory in Northumberland. This isn't part of the book because it was too late, but we saw this thing called 'noctilucent clouds'. They are like these amazing features. Basically it's where clouds form really high up in the sky, and the Sun has already set, but because the clouds are so high, they can reflect the light off the set Sun. Although it's dark, and you can't see the Sun, the clouds are so high that they reflect the light and give this blue-and-white shimmer. It's literally the most beautiful thing I've ever seen.

> "The vastness of space can actually be very overwhelming and make us feel completely insignificant"

THE HUNT FOR EARTH'S SISTER

An ESA mission about to blast off hopes to study exoplanets in more detail

Reported by Ian Evenden



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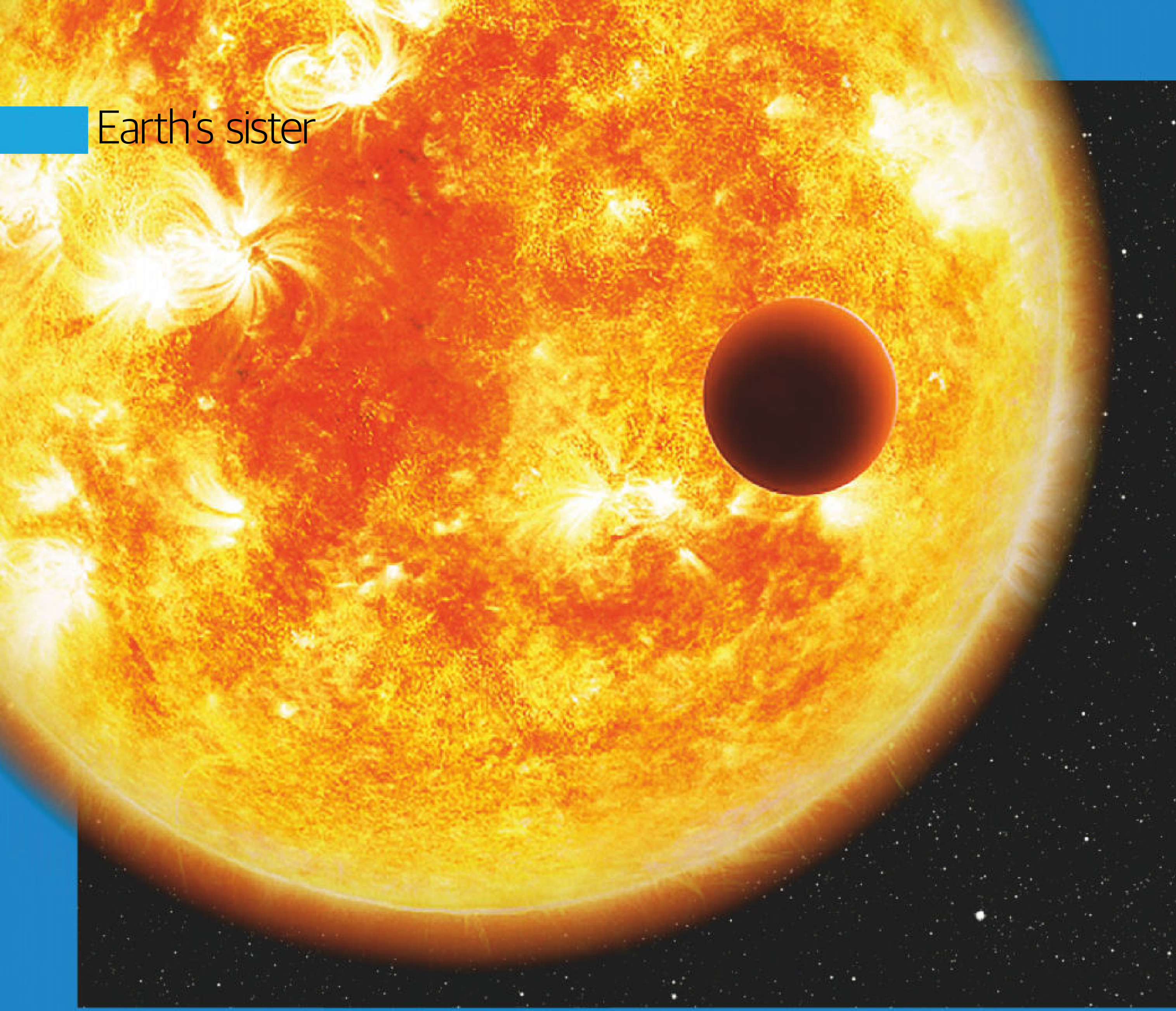
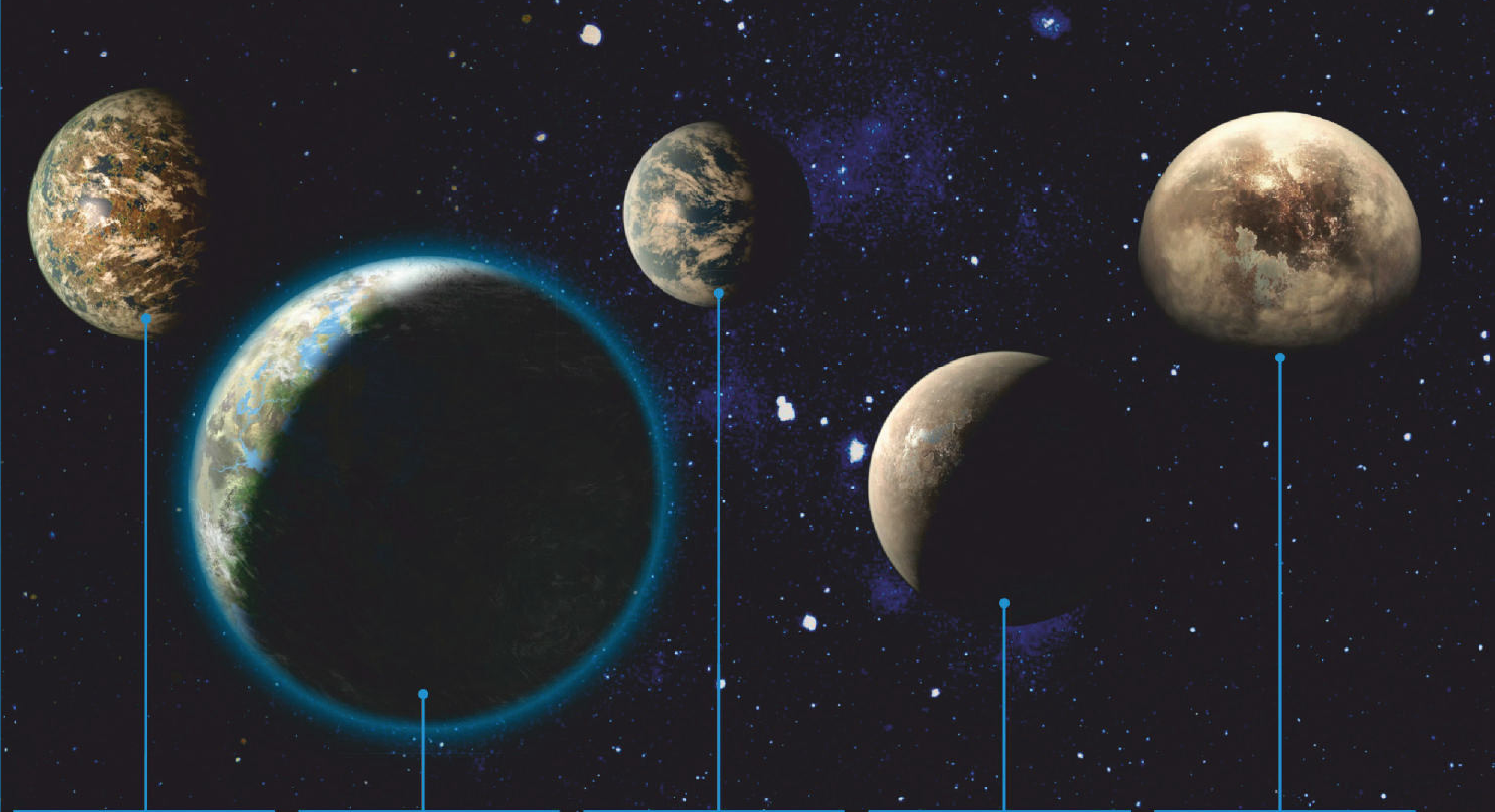


Earth is, as far as we know, unique in the universe for bearing life. What's not unique about it is that it's a rocky ball orbiting at a distance from its star that allows liquid water to exist on its surface. The number of these planets we know of is quite large, and is getting bigger all the time.

Since the discovery of the first confirmed exoplanet in 1992, we've found over 4,000 planets orbiting more than 3,000 stars. Earth isn't alone in the universe, and humanity is launching more planet-hunting missions to discover just how large its family is. One of these is CHEOPS, the CHaracterising ExOPlanet Satellite from the European Space Agency (ESA), which will blast off on a Soyuz ST-B rocket later this year. It is the first S-class, or 'small' mission in the ESA's Cosmic Vision programme. CHEOPS actually has a rather large task: rather than discovering new exoplanets, it will reanalyse those already known and attempt to accurately measure their size. Its targets will all be in the range of one to six Earth radii, from Earth-like planets to those known as super-Earths, and to some the size of Neptune.

Top 'Earth-like' worlds

How do other planets found so far compare to our homeworld?



	TRAPPIST-1e	Gliese 581g	TRAPPIST-1d	Proxima Centauri b	Ross 128 b
Discovered:	2017	2010	2016	2016	2017
Distance:	40 light years	20 light years	40 light years	4.2 light years	11 light years
Mass:	0.62 Earths	4.0 Earths	0.41 Earths	1.27 Earths	1.4 Earths
Orbit:	6.1 days	37 days	4.05 days	11.2 days	9.9 days
Star type:	Ultracool dwarf	Red dwarf	Ultracool dwarf	Red dwarf	Red dwarf
Earth Similarity Index:	0.95	0.92	0.89	0.87	0.86

Left: Artist's impression of an exoplanet transiting a star. This causes a dip in the star's output, which can be measured

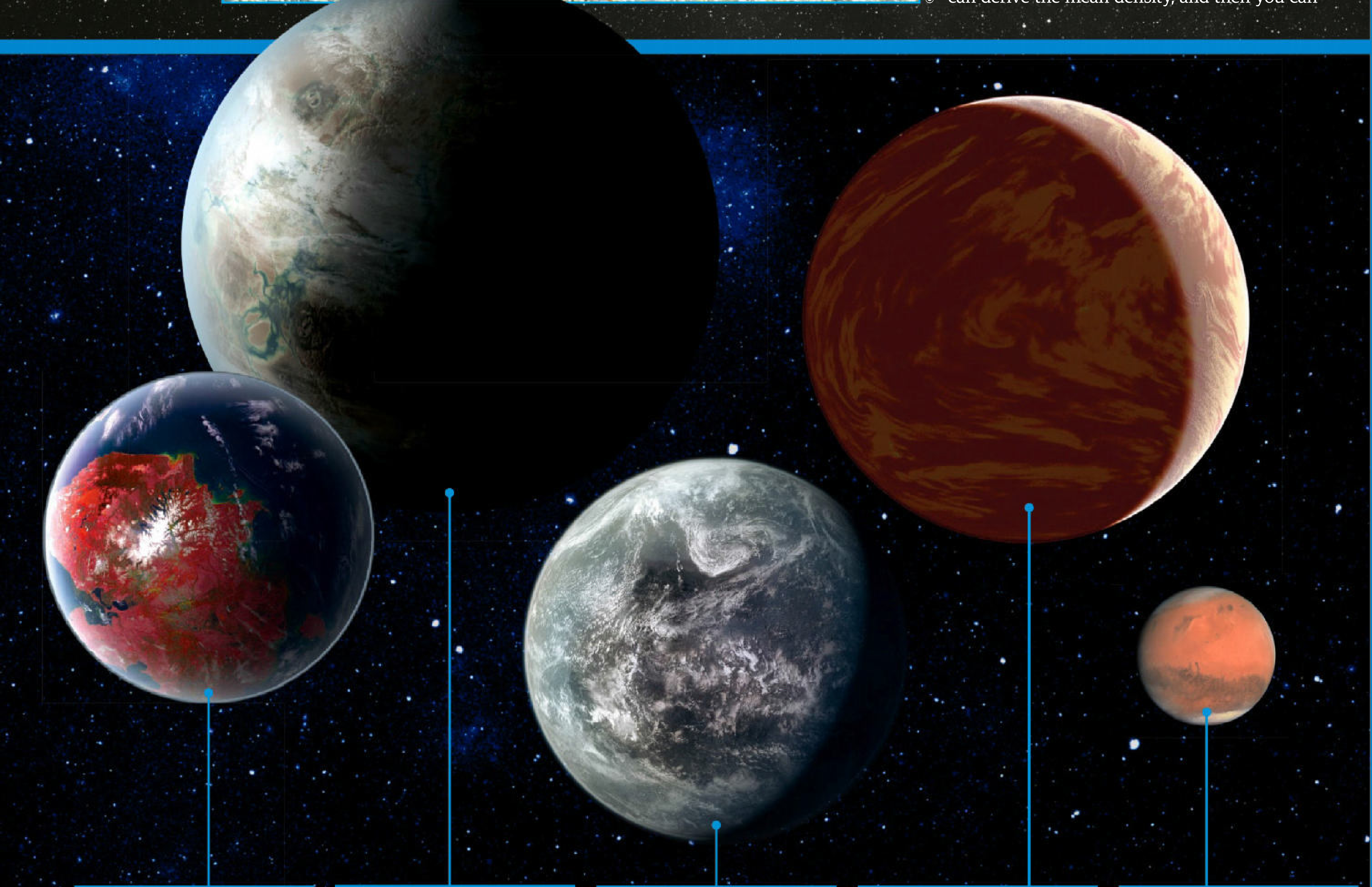
Right: CHEOPS' mission operations centre in Torrejón de Ardoz, Spain. Here spacecraft operators will configure and manoeuvre the satellite

© NASA

CHEOPS' measurements of planetary radii should be accurate to within ten per cent thanks to its high-precision Ritchey-Chrétien telescope, which uses mirrors designed to eliminate all optical errors such as coma.

The satellite's targets will be planets around bright and nearby stars, many of them found by NASA's Transiting Exoplanet Survey Satellite (TESS). Professor Willy Benz from the University of Bern, Switzerland, principal investigator for CHEOPS, makes it clear that it's not a discovery mission, but a follow-up mission. "Follow-up means that we know the star, we know that the star has a planet, and what we want is to measure that planet with more precision. We're not out there to discover planets, we're out there to refine what we know about those we know already exist."

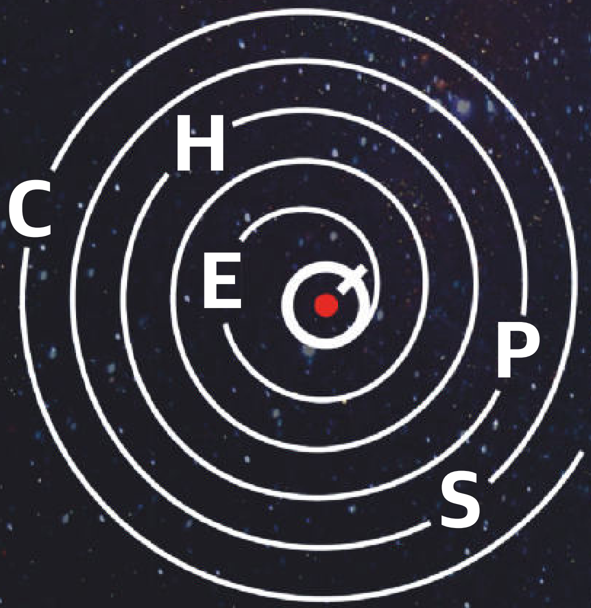
Measuring the radius of a planet combines with other data to tell you something very special: the planet's composition. "We're interested in going beyond knowing the mass of these exoplanets," says Benz. "We want to know their radii. Because once you have mass and radius you can derive the mean density, and then you can



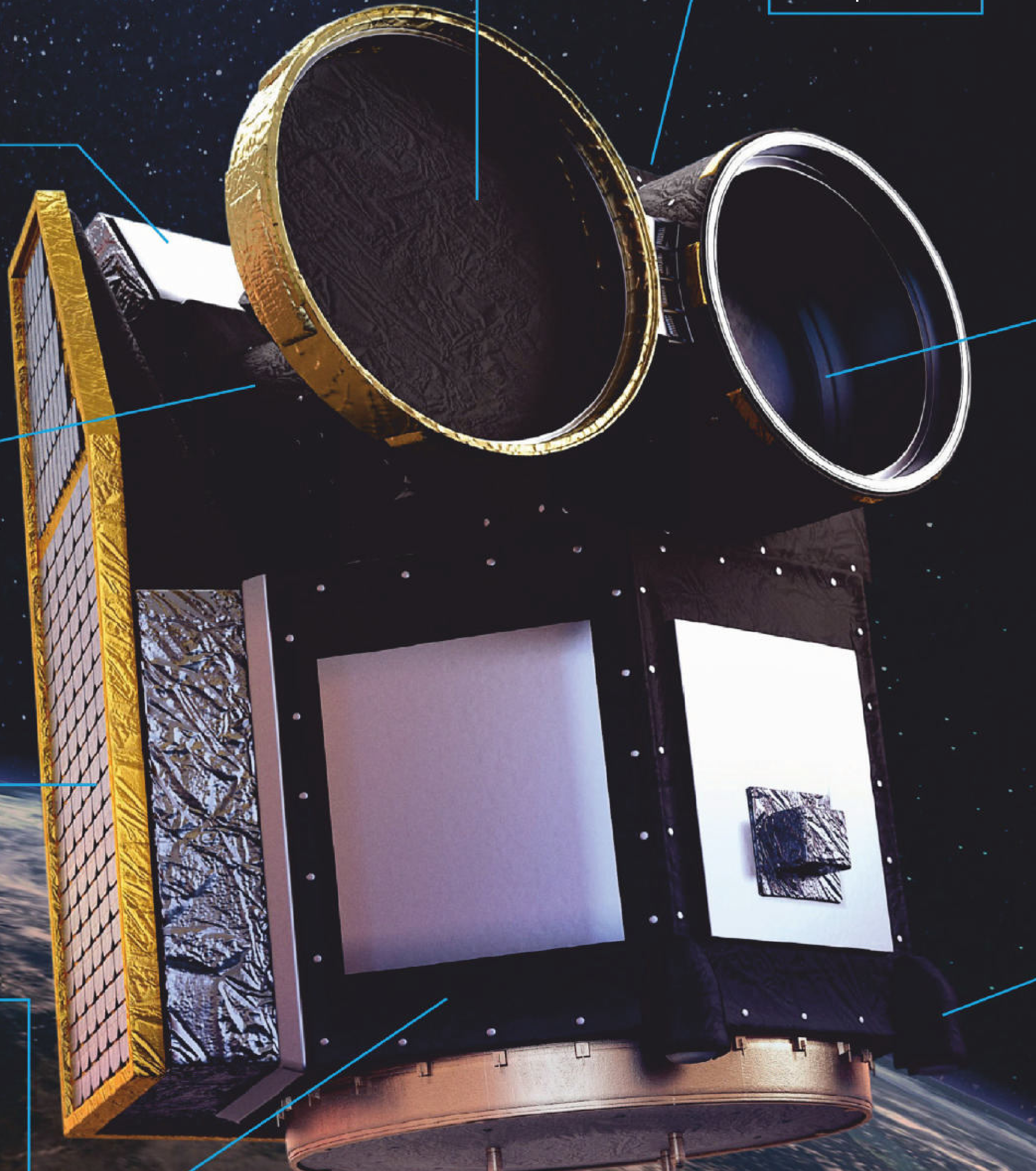
	Kepler-442b	Kepler-452b	HD 85512 b	Wolf 1061c	Mars
Discovered:	2015	2015	2011	2015	Antiquity
Distance:	1,116 light years	1,829 light years	37 light years	14 light years	225 million km
Mass:	2.36 Earths	3.29 Earths	3.18 Earths	3.41 Earths	0.11 Earths
Orbit:	112.3 days	384.8 days	58.4 days	17.9 days	687 days
Star type:	K-type	G-type	K-type	Red dwarf	G-type
Earth Similarity Index:	0.84	0.83	0.77	0.76	0.73

CHEOPS: the new exoplanet hunter

A compact spacecraft based on proven ESA technology, the mission has a few unique features



CONSORTIUM
FOR HALL
EFFECT
ORBITAL
PROPULSION
SYSTEM



Lens cap
To keep the instrument free of dust, this cap is kept in place. A spring-loaded mechanism will open it once in orbit.

S-band transmitters
Communications between CHEOPS and ground control is through redundant S-band transceivers. The transmitters are at the top.

Radiator
Kept pointing into interplanetary space, the radiator passively cools the telescope to -40°C (-40°F) to minimise noise.

Star trackers
Hidden behind the body in this image, CHEOPS' two star trackers keep it perfectly aligned with its targets.

Solar array
Wrapped around three sides of the spacecraft and helping to block stray light, the array can produce up to 200W of power.

Main body
In here are the avionics that allow the satellite to fly, along with the computers that run it and the photometry analysis.

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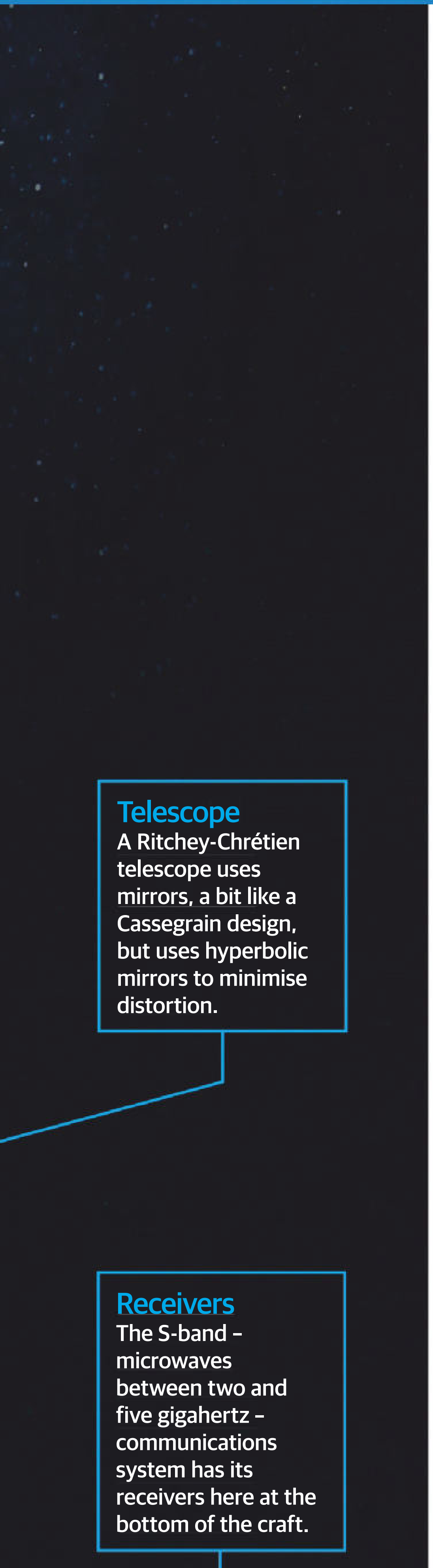


Telescope
A Ritchey-Chrétien telescope uses mirrors, a bit like a Cassegrain design, but uses hyperbolic mirrors to minimise distortion.

Receivers
The S-band – microwaves between two and five gigahertz – communications system has its receivers here at the bottom of the craft.

Above: The CHEOPS satellite in the clean room at Airbus Madrid, February 2019. The technician gives a handy sense of scale

Below: Principal investigator Willy Benz with a half-scale model of the CHEOPS satellite

know whether the object is made of rock, of gas, of water or ice and so on.

"We worked on the proposal for CHEOPS as early as 2008," says Benz, who has been with the project since its inception. "We did a feasibility discovery but realised that the mission would be too expensive for Switzerland alone. We started looking at possibilities to get it done in collaboration, and it so happened that the ESA put out a call for small missions in 2012. We modified a few things to tailor it to the needs of the ESA, submitted it and eventually got selected."

Once CHEOPS launches later this year, it will orbit Earth from 700 kilometres (435 miles) away with its back pointed permanently in the direction of the Sun. This enables its wraparound solar panels to shield the telescope aperture from sunlight, simultaneously generating power and allowing the telescope to concentrate on starlight from other systems without interference from our inconveniently nearby yellow dwarf.

The method it uses to observe exoplanets is called photometry, a measurement of the flux, or intensity, of light emanating from an astronomical object. If a star has an orbiting planet - and it's facing the right way - the light output will dip when the planet passes across the face of the star, known as a transit.

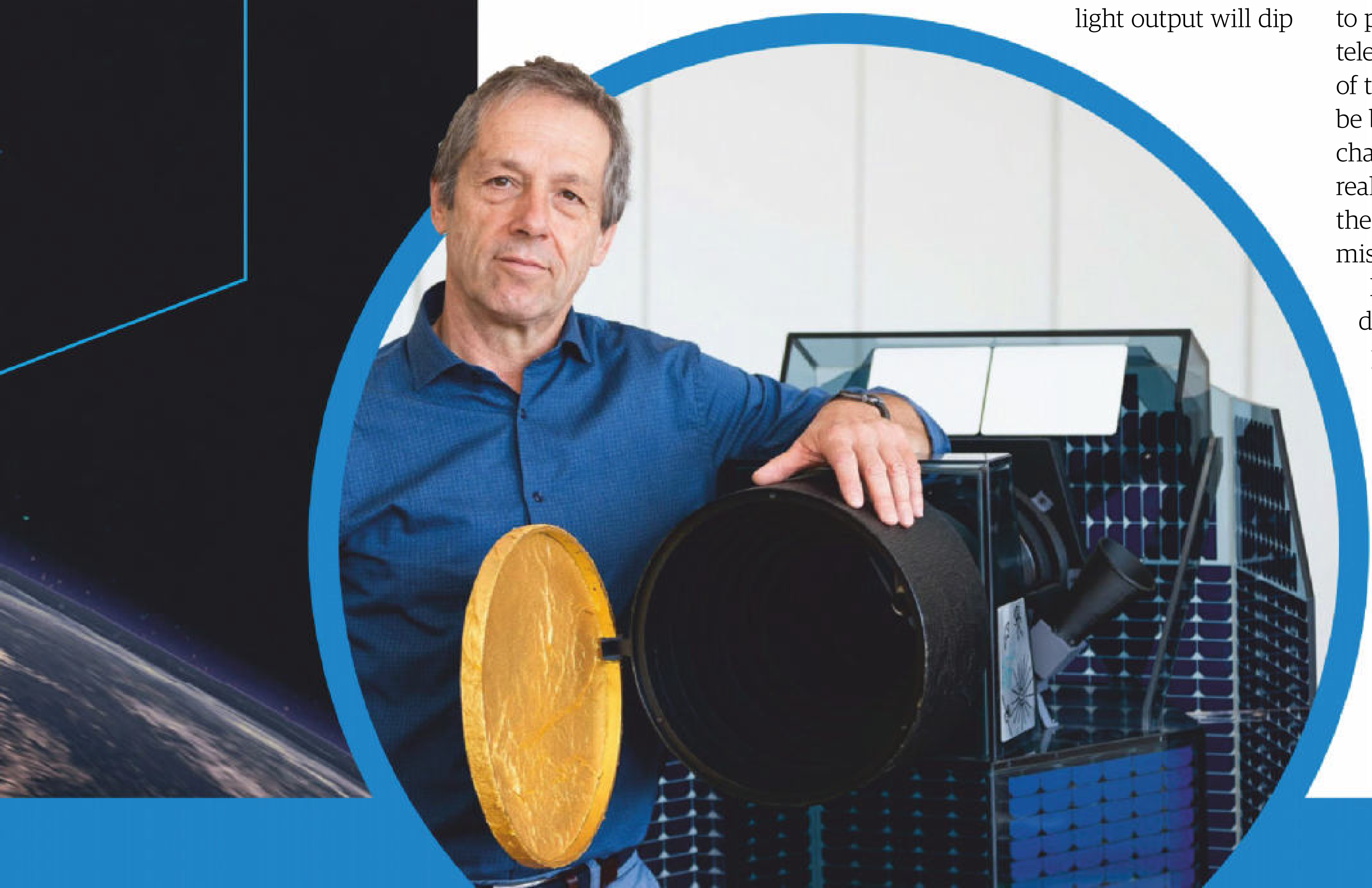
We spoke to Professor Hugh Jones from the Centre for Astrophysics Research at the University of Hertfordshire, who is not involved with CHEOPS, to find out how the technique works. "It's all about the planet blocking the light from the star in a regular time interval," he says. "If you keep staring at a star and its output changes by a small amount every so often, and that happens to be completely regular, then there aren't many things a star can do that are completely regular other than be blocked out by a planet. It's very easy to get confused with background stars, or in binary systems where you can't resolve the stars properly. Star activity and stellar phenomena like sunspots don't happen regularly - they are infamously difficult to understand and predict - but one thing they're not is completely regular. A planet in orbit, regularly blocking out the light, gives a distinctive signature.

"The reason for putting a telescope in space is to get rid of the problems associated with the Earth's atmosphere," Jones continues. "If you want to see something happen regularly, it's a real pain to miss it because it happens to be daytime where you are, or cloudy or raining. It becomes quite difficult to pick up regular events from one ground-based telescope. The signals are really small - one per cent of the light is the most that a planet would probably be blocking, probably less, so looking at a tiny change in the light output from the star requires a really stable instrumental set-up with no changes in the conditions, and that's exactly why this satellite mission has gone into space."

Planet-hunting 'scopes can use photometry to discover not only if a planet is there, but also its period - the amount of time it takes to orbit its star. From that you can work out a lot more.

"From its period you can know the distance to its star," says Benz. "The planets go around the star, and if you know what kind of star and the mass of the star then the period gives you the distance. Typically the Earth goes around the Sun in one year; from that I can tell you how far away from the Sun the Earth is."

The list of target stars for CHEOPS is still under wraps, but Benz offers up hope if your



Past, present and future exoplanet missions

CHEOPS isn't the first space telescope studying other worlds, nor will it be the last

2003

MOST

Launch date: 2003
End date: 2019

The Microvariability and Oscillations of Stars mission was Canada's first space telescope and one of the earliest space-based exoplanet hunters. It was also quite small, picking up the nickname 'the Humble Space Telescope'. In 2011 it detected transits of the star 55 Cancri A by an exoplanet – up to five are now thought to orbit the star.

2009

Kepler

Launch date: 2009
End date: 2018

A telescope specifically designed to detect planets around other stars, Kepler is notable for promising much, but massively over-delivering on its mission. Originally planned to last 3.5 years, Kepler eventually ran out of fuel nine years and seven months after launch, having observed 530,506 stars and discovering 2,662 planets.

2013

Gaia

Launch date: 2013
End date: 2022 to 2024

An ESA mission aiming to collect the largest astronomical catalogue yet, Gaia is targeting around one per cent of stars in the Milky Way, all above magnitude 20, of which it will make a precise 3D map. It is also expected to discover quasars and exoplanets outside our Solar System, and new asteroids and comets within it.

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2017

ASTERIA

Launch date: 2017
End date: Unknown

The Arcsecond Space Telescope Enabling Research in Astrophysics is a tiny technology demonstrator from NASA that may become part of a swarm of cubesats monitoring multiple targets at once for longer periods, also identifying new targets for other telescopes to observe. It is currently searching for exoplanets around nearby bright stars.

Water detected in exoplanet atmosphere

The planet lies in the habitable zone around its host star, but is too large to be another Earth

Using data from the Kepler, Spitzer and Hubble space telescopes, teams of researchers in London and Montréal have reported the discovery of water vapour in the atmosphere of an exoplanet in its star's habitable zone, making it the first known world with both water and temperatures that could support life.

K2-18b is far from being Earth's twin, however. Twice as big and eight-times heavier than Earth, the planet takes just 33 days to swoop around its star, to which it may be tidally locked, just as the Moon is to Earth. Its equilibrium temperature is thought to be one degree Celsius (33.8 degrees Fahrenheit), and it receives approximately 94 per cent of the sunlight Earth does, but a thick atmosphere of hydrogen and helium, along with 20 to 50 per cent water vapour, could radically change this. The water vapour is abundant enough to form clouds.

At 111 light years distant the red dwarf star K2-18 has a greater ultraviolet output than our Sun, but is dim enough to make analysis of the planet's atmosphere possible. It is expected to be a target for NASA's upcoming JWST, along with the ESA's ARIEL programme, which when it launches in 2028 will study the atmospheres of at least 1,000 exoplanets.

favourite exoplanet isn't one of those chosen for further investigation: 20 per cent of the telescope's observing time will be open to guest observers, and can be used to study targets not on the official list. A committee will select proposals based on scientific merit. This will also allow important newly discovered targets to be observed without having to wait until they're on the approved lists. "Anybody from around the world can submit a proposal," says Benz. Furthermore, and of great interest to citizen scientists, the CHEOPS data will become public after a year.

The list contains a mix of planets discovered by earlier planet-hunting missions such as Kepler and TESS. "Not so much the Kepler targets, because on average those are faint," says Benz. "The idea is to get brighter targets, so we are following more TESS targets. TESS is flying today and is discovering a lot of planets, but its telescope is much smaller than that in CHEOPS, so what we can do on some of the most interesting TESS targets is to refine the measurement of the radius to make it more precise. It has to be precise if you want to infer something about the composition of the planet."

And while the big planet-hunting missions can detect exoplanets around stars thousands of light years away from Earth – the record at the time of writing being SWEEPS-11 and -04 orbiting a star 27,710 light years away in the constellation Sagittarius, and one that may have been found 2.5 million light years away in the Andromeda galaxy thanks to gravitational lensing enhancing the view of a red giant star – CHEOPS' preference for brighter stars constrains it to somewhat closer targets. "The type of star, plus the distance to the star, determines how bright it is in the end," says Benz. "We're talking about distances of tens of light years."

Considering such distances, and with precision the name of the game, CHEOPS has been engineered to protect itself from potential sources of interference. "The difficulty of the mission was to devise an optical system that allows us to use ultra-precise photometry," says Benz. "It has a number of features that aim to reject stray light. That's the number one enemy. It comes from light from the Sun, reflected sunlight from the Earth, reflected sunlight from the Moon that gets into the telescope, so the telescope has been engineered with a number of baffles to reject the maximum amount of light that does not come from the target star.

"The second challenging part is to have the detector's readout electronics generate very low noise," Benz continues. "If you have no stray light, but your CCD is read out by electronics that generate a lot of noise, then you haven't gained anything. We need an image that is as low-noise as possible."

Given that these planets are many light years removed from our own Solar System, and with current levels of technology we will never be able to visit them, why study them at all? We know they're there, isn't that enough? Benz does not think so:

> "TESS is flying today and is discovering a lot of planets, but its telescope is much smaller than that in CHEOPS" **Willy Benz**

2018

TESS

Launch date: 2018
End date: Planned for 2020

The Transiting Exoplanet Survey Satellite is a NASA mission searching for exoplanets in an area 4,000-times larger than that covered by Kepler. TESS almost immediately found a new comet after beginning its observations and discovered its first exoplanet after less than two months; a super-Earth orbiting the yellow dwarf Pi Mensae.

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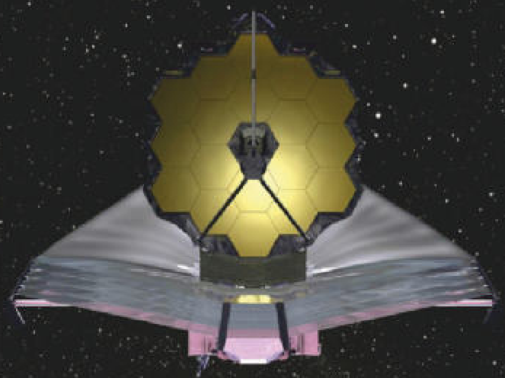


2021

JWST

Launch date: Planned for 2021
End date: Five-year design life

Hubble's successor, the JWST will use its mirror to observe in wavelengths ranging from long visible light to the mid-infrared, meaning it can see high-redshift objects that are very old. Exoplanet hunting is also part of its brief, using a direct imaging technique rather than photometry. This works best on planets that emit infrared light.

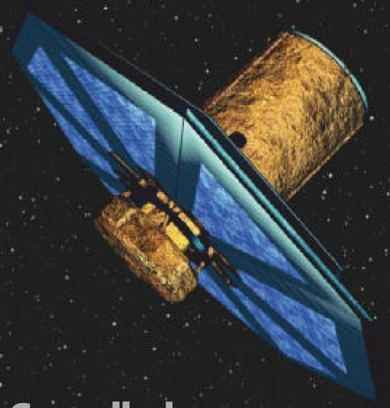
© NASA

2028

ARIEL

Launch date: 2028
End date: Four-year mission plan

The Atmospheric Remote-sensing Infrared Exoplanet Large-survey is an ESA telescope that will observe 1,000 planets orbiting distant stars and make a survey of their chemistry. It will carry a reflecting telescope and a spectrometer to detect the chemical fingerprints of gases in the planets' atmospheres. It will focus on warm planets orbiting close to their stars.



Cancelled

Darwin

Launch date: Proposed in 1993
End date: Cancelled in 2007

A set of three free-flying space telescopes positioned beyond the Moon, Darwin was a proposed ESA mission to observe extrasolar planets and produce very high-resolution infrared images at least ten-times more detailed than the JWST's. While Darwin never took off, both the ESA and NASA have considered similar missions since.

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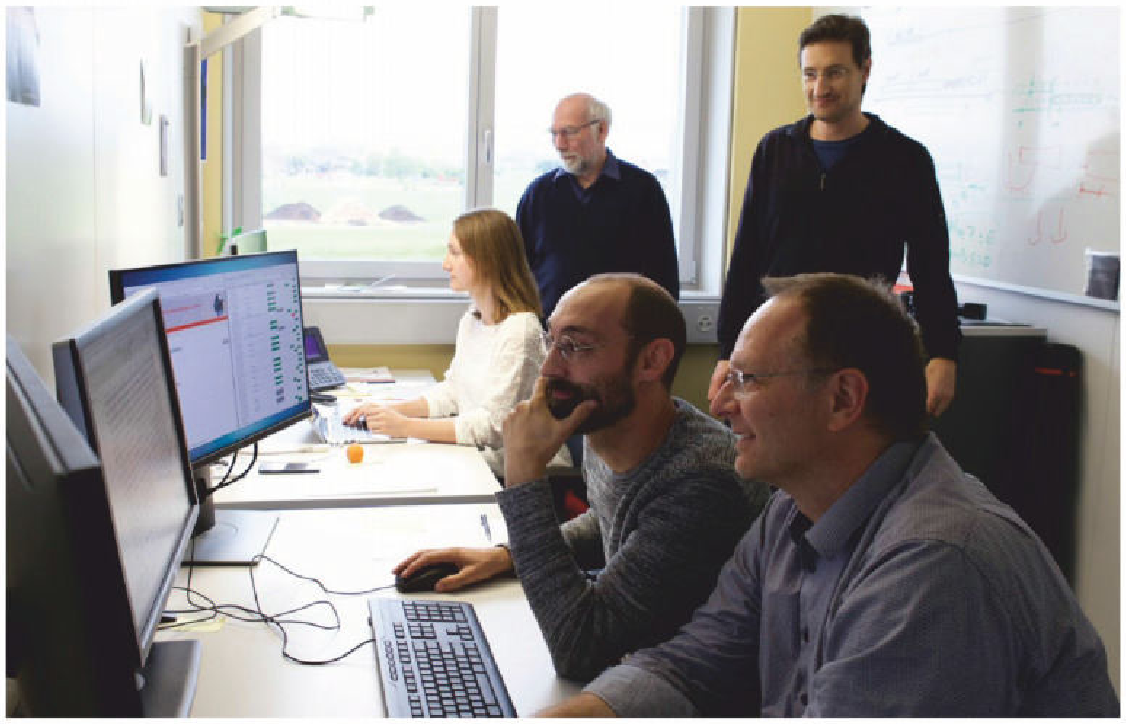
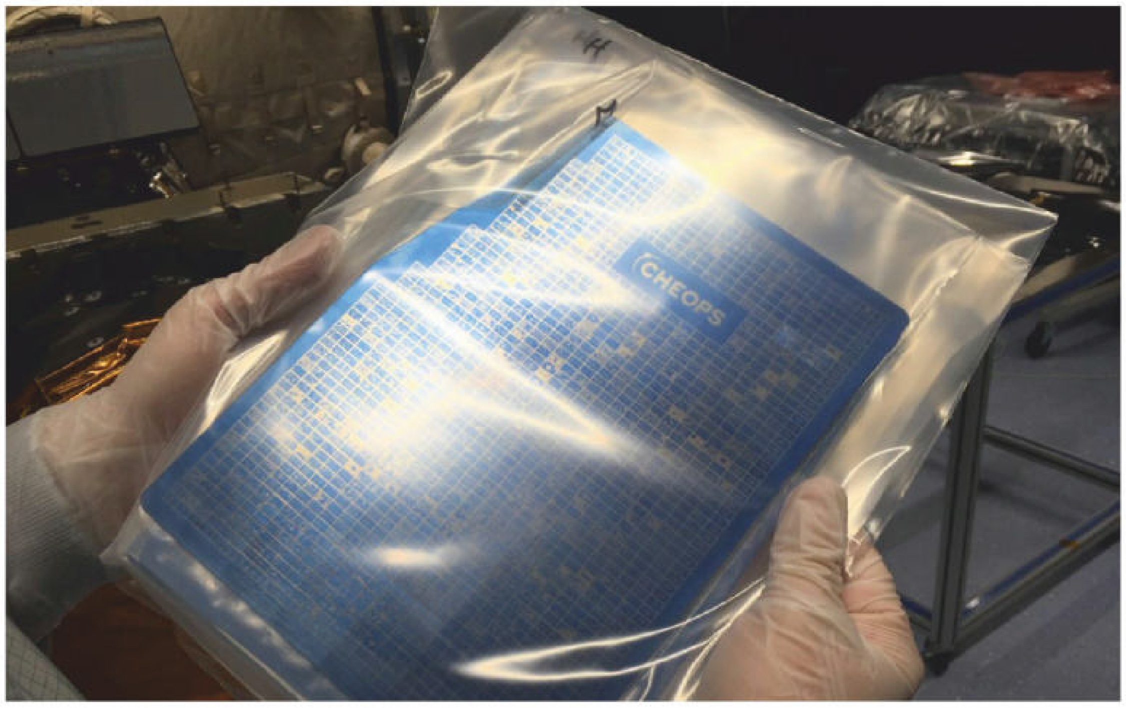




Left: The CHEOPS science team undertaking a rehearsal at their Switzerland HQ. Principal investigator Willy Benz is closest to the camera

Below: One of two titanium plaques CHEOPS will launch with, carrying the drawings of 2,700 children aged between 8 and 14 into orbit

"Once you know a planet is there, don't you think you'd like to know what they are made of, how hot they are? Do they have water? What they look like? Once you know it's there you want to characterise it, to go one step further. You're curious. Curiosity is driving the whole field. We know of thousands of exoplanets, now we want to know more than just that they exist."

Jones agrees: "We have our own planets with a set of properties, and the initial searches for exoplanets were based on looking for planets with properties like our own Solar System, and that's not what we've really found. We've found planets with a whole range of different properties, and the subject has become much bigger and more interesting than we imagined. The first exoplanets found around solar-type stars were Jupiter-sized or bigger, going around in orbits of a few days, much faster than Mercury's 88-day orbit. That's an example of how extreme things are.

"Knowing the radius plus a mass estimate is telling you something about the planet's potential history," he continues. "Planets might not stay in exactly the same orbits they're born in, and they might acquire more material, moons or rings. It's only with really good data that you can discriminate between different theoretical models. It extends into understanding our own planets and their formation. Our ideas about the formation of the Solar System have been completely changed by discoveries of planets going around other stars."

In an extreme universe, it seems gathering more and more data is the key to knowing just how extreme things can get. The search for Earth-like planets may keep headline writers busy, but data from every planet CHEOPS and other space telescopes survey will play its role in understanding how the universe came to be the way it is today.

IN COOPERATION WITH SPACE.com

HELICOPTER SCOUT INSTALLED ON MARS ROVER

The first-ever off-Earth 'chopper' just hooked up with its travelling companion

Reported by Mike Wall

Engineers at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California, attached the tiny Mars Helicopter Scout to the agency's car-sized Mars 2020 rover on 28 August, agency officials announced.

The duo will launch together in July 2020, touching down inside the Red Planet's Jezero Crater in February 2021. Once on Mars the solar-powered, 1.8 kilogram (four pound) helicopter will detach and begin flying test sorties.

"Our job is to prove that autonomous, controlled flight can be executed in the extremely thin Martian atmosphere," MiMi Aung, project manager of the Mars Helicopter, said in a statement. Mars' air is just one per cent as dense as that of Earth at sea level.

"Since our helicopter is designed as a flight test of experimental technology, it carries no science instruments," she added. "But if we prove powered flight on Mars can work, we look forward to the day when Mars helicopters can play an important role in future explorations of the Red Planet."

For example, helicopters could serve as scouts for robots or human pioneers on Mars. Red Planet rotorcraft could also carry instruments and conduct a variety of science work of their own, NASA officials have said.

Mars 2020, which will soon get a catchier moniker via a student naming competition, will hunt for signs of long-dead Red Planet life in Jezero Crater, which hosted a river delta in the ancient past. The rover will also characterise the site's geology, collect and cache samples for future return to Earth and demonstrate gear that will generate oxygen from the carbon dioxide-dominated Martian air, among other tasks.

"With this joining of two great spacecraft, I can say definitively that all the pieces are in place for a historic mission of exploration," Thomas Zurbuchen, associate administrator of the Science Mission Directorate at NASA's headquarters in Washington, DC, said in the same statement. "Together Mars 2020 and the Mars Helicopter will help define the future of science and exploration of the Red Planet for decades to come."

NASA plans to launch another rotorcraft soon as well – Dragonfly – which will soar through the thick atmosphere of Saturn's huge moon Titan. The life-hunting Dragonfly is scheduled to liftoff in 2026 and land on Titan's frigid surface in 2034.

> "Since our helicopter is designed as a flight test of experimental technology, it carries no science instruments" **MiMi Aung**

Above: JPL engineers prepare the helicoper and rover for deployment next year

Far left: The Jezero Crater is the planned landing site for the robotic duo

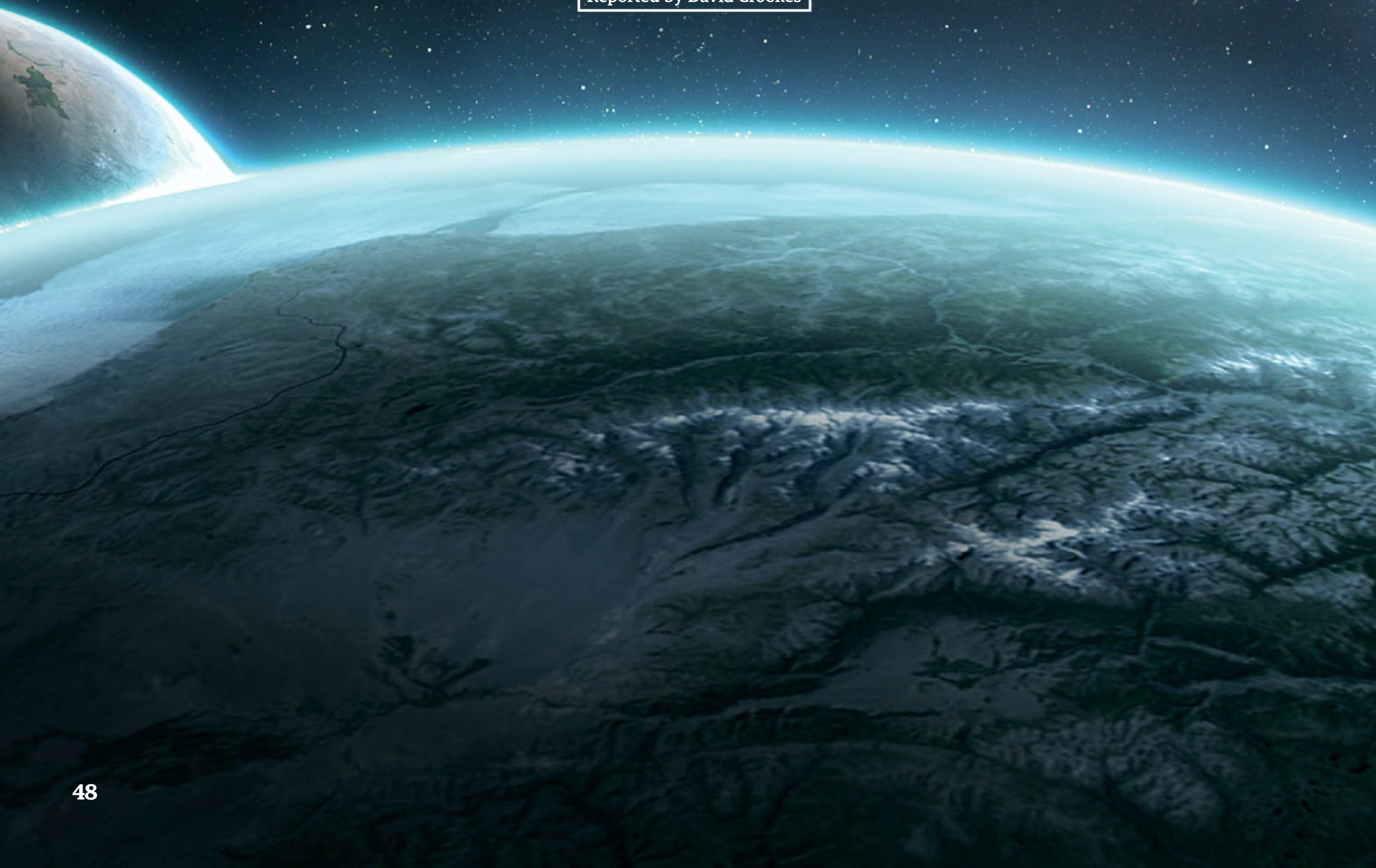
© NASA

MYSTERIES OF THE UNIVERSE

HOW CAN A STAR BE OLDER THAN THE UNIVERSE?

Astronomers seeking an accurate age for the cosmos continue to be baffled by an ancient star that appears to be even older

Reported by David Crookes



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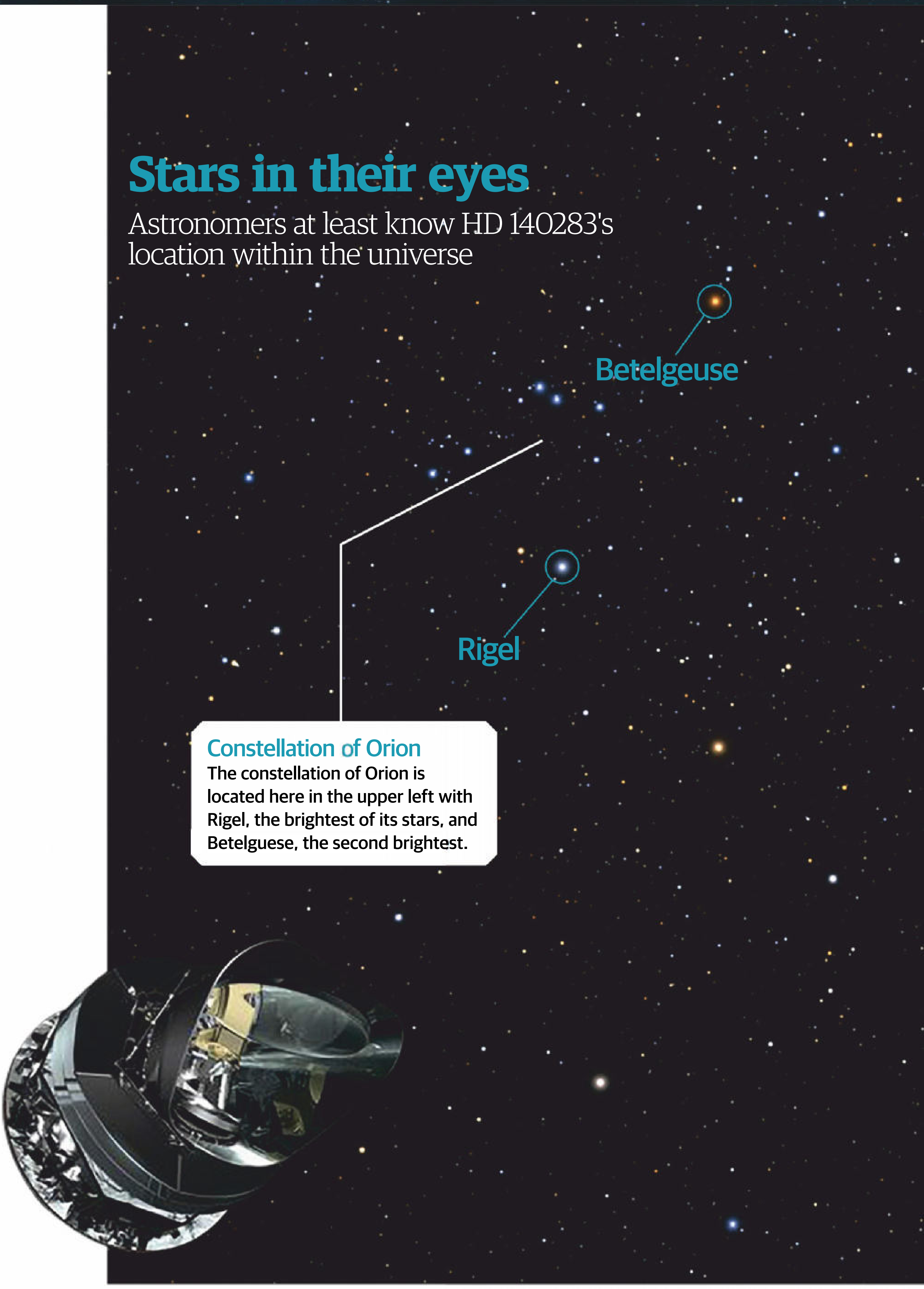
Stars in their eyes

Astronomers at least know HD 140283's location within the universe



Constellation of Orion
The constellation of Orion is located here in the upper left with Rigel, the brightest of its stars, and Betelguese, the second brightest.

For more than 100 years, astronomers have been observing a curious star located some 190 light years away from Earth in the constellation Libra. It rapidly journeys across the sky at 1.3 million kilometres (800,000 miles) per hour. But, more interesting than that, HD 140283 - or Methuselah as it's commonly known - is also one of the universe's oldest known stars.

In 2000 scientists sought to date it using observations via the European Space Agency's (ESA) Hipparcos satellite that estimated an age of 16 billion years old. Such a figure was quite impressive, and rather mind-blowing, yet also pretty baffling. As Professor Howard Bond of Pennsylvania State University points out, the age of the universe - determined from observations of the cosmic microwave background - is 13.8 billion years old. “It was a serious discrepancy,” he tells us.

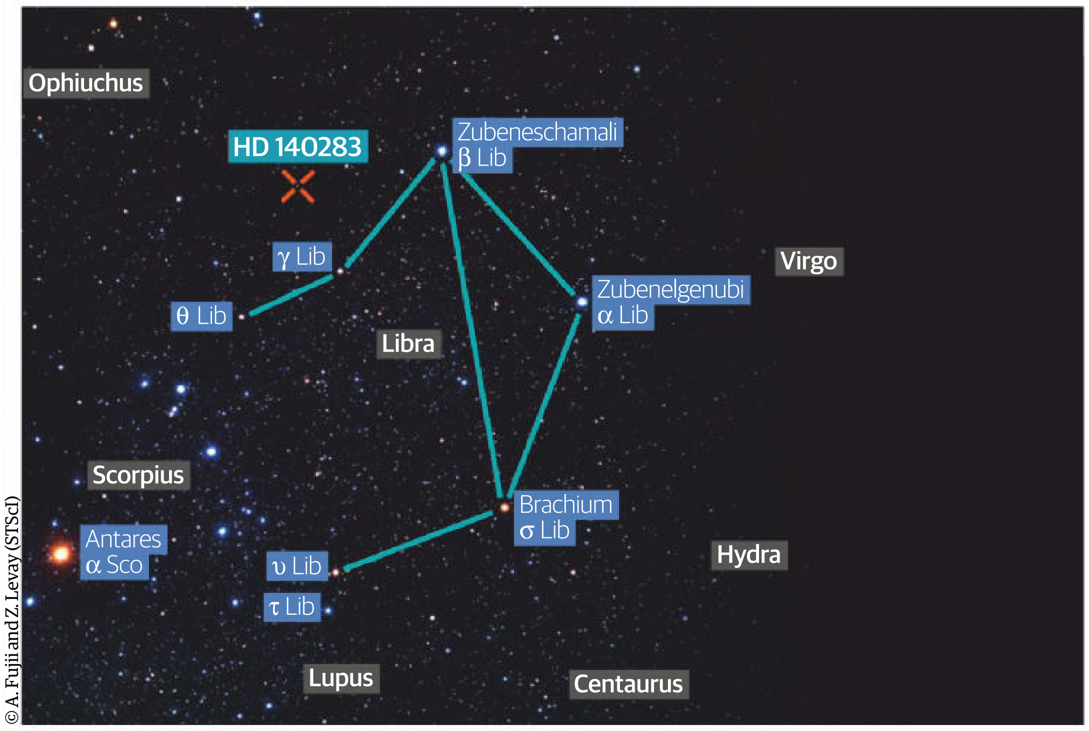
Taken at face value, it raised a major problem. How could a star be older than the universe? Or, conversely, how could the universe be younger? It was certainly clear that Methuselah - named in reference to a biblical patriarch who is said to have died aged 969, making him the longest lived of all the figures in the Bible - was old, since the metal-poor subgiant is predominantly made of hydrogen and helium and contains very little iron. It meant it must have come into being before the element became commonplace. But more than two billion years older than its environment? Surely that is just not possible.

Bond and his colleagues set themselves the task of figuring it out, and the first step was determining whether that initial figure of 16 billion was actually accurate. They pored over 11 sets of observations that had been recorded between 2003 and 2011 by the Fine Guidance Sensors of the Hubble Space Telescope, which make a note of the positions, distances and energy output of stars. In acquiring parallax, spectroscopy and photometry measurements, a better sense of age could be determined.

“One of the uncertainties with the age of HD 140283 was the precise distance of the star,” Bond explains. “It was important to get this right because we can better determine its luminosity, and from that its age - the brighter the intrinsic luminosity, the younger the star. We were looking for the parallax effect, which meant we were viewing the star six months apart to look for the shift in its position due to the orbital motion of the Earth, which tells us the distance.”

There were also uncertainties in the theoretical modelling of the stars, such as the exact rates of nuclear reactions in the core and the importance of elements diffusing downwards in the outer layers, he adds. They worked on the idea that leftover helium diffuses deeper into the core, leaving less hydrogen to burn via nuclear fusion. With fuel used faster, the age is lowered.

“Another factor that was important was, of all things, the amount of oxygen in the star,” Bond continues. Indeed, HD 140283 had a higher than predicted oxygen-to-iron ratio and, since oxygen



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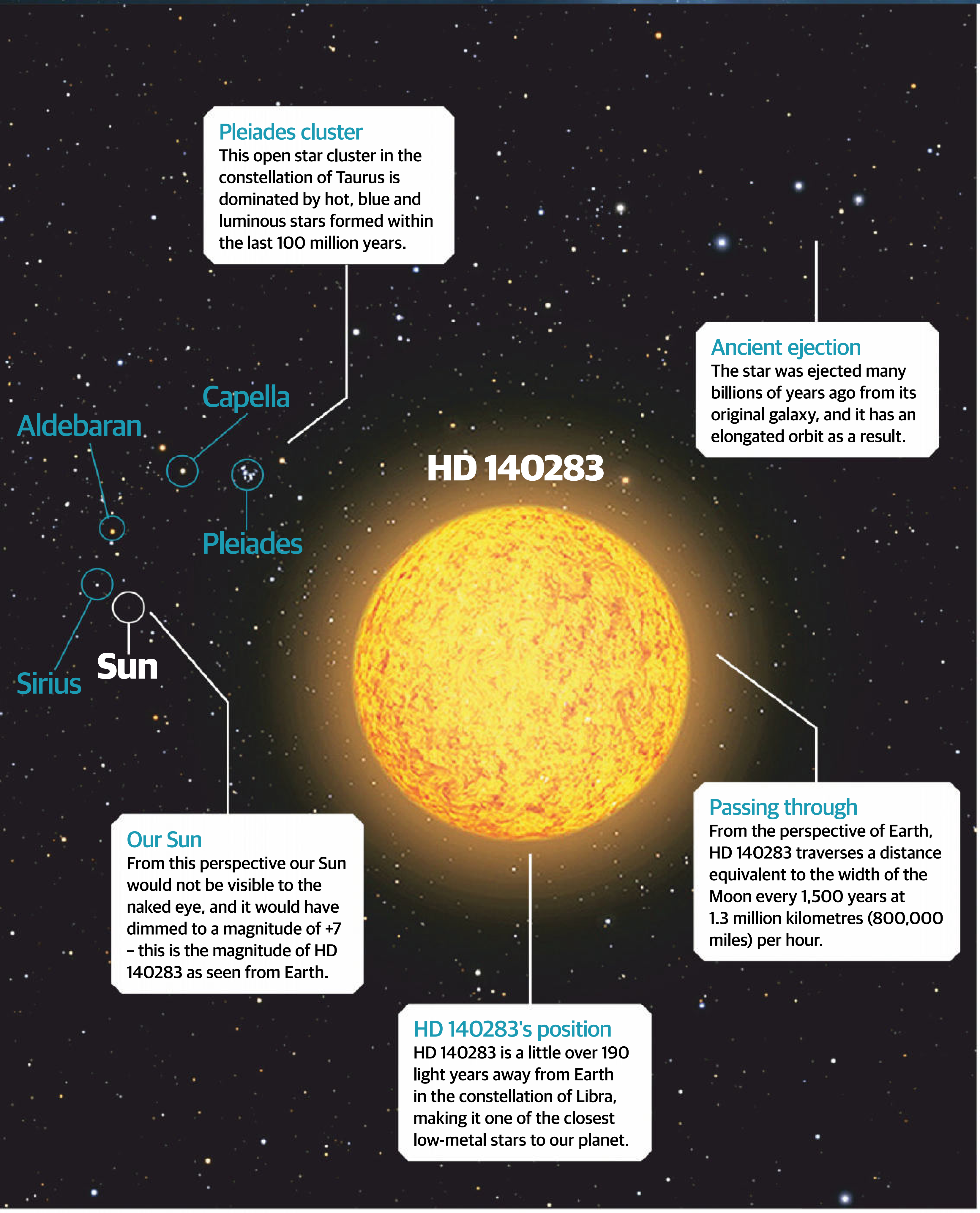
Left:
A view of the sky surrounding HD 140283 in an image that was released in 2013

Far right:
A Digitized Sky Survey image of HD 140283 which was photographed by the Anglo-Australian Observatory in 2013



Pleiades cluster
This open star cluster in the constellation of Taurus is dominated by hot, blue and luminous stars formed within the last 100 million years.

Ancient ejection
The star was ejected many billions of years ago from its original galaxy, and it has an elongated orbit as a result.

Our Sun
From this perspective our Sun would not be visible to the naked eye, and it would have dimmed to a magnitude of +7 – this is the magnitude of HD 140283 as seen from Earth.

Passing through
From the perspective of Earth, HD 140283 traverses a distance equivalent to the width of the Moon every 1,500 years at 1.3 million kilometres (800,000 miles) per hour.

HD 140283's position
HD 140283 is a little over 190 light years away from Earth in the constellation of Libra, making it one of the closest low-metal stars to our planet.

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Methuselah by numbers

HD 140283
The official name for the subgiant star

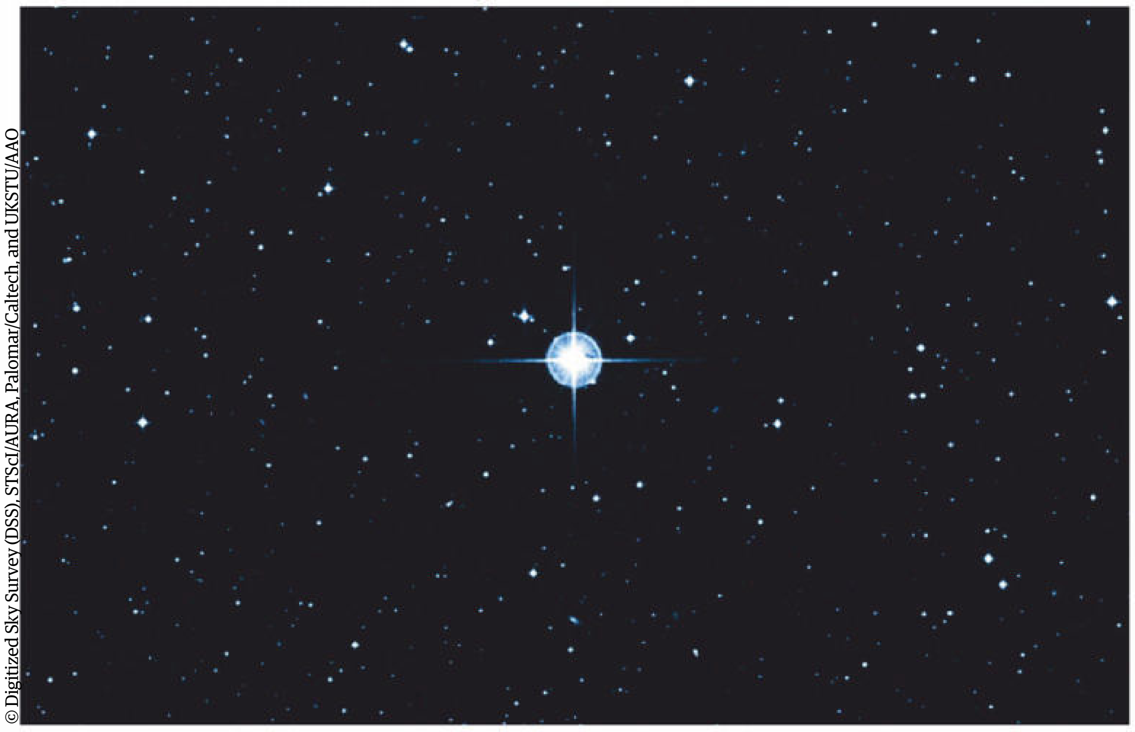
190.1
Number of light years away from Earth

14.5 billion
Potential age of the star in years

0.780
Estimated solar mass

5,787±48
Estimated temperature in Kelvin

974,000
Star's radius in kilometres



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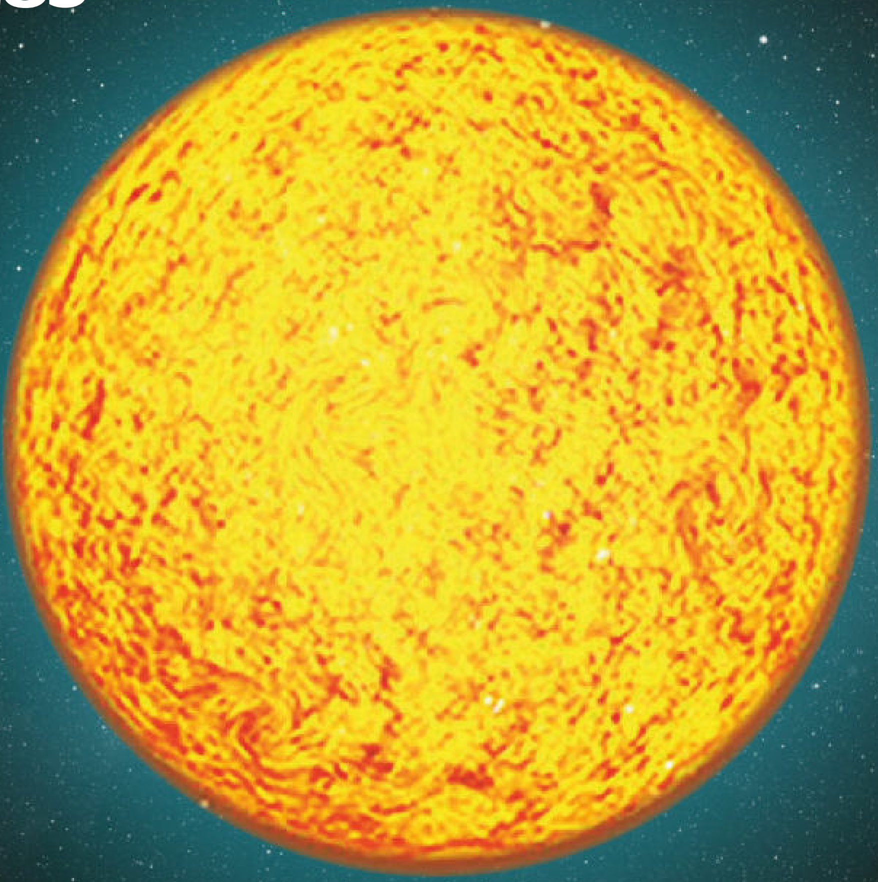
A study by Inh Jee of the Max Planck Institute in Germany and published in *Science* magazine on 13 September 2019 used gravitational lensing to suggest a Hubble Constant of 82.4, which would age the universe at 11.4 billion years. It does, however, have a large margin of error because only two gravitational lenses were used.

What is HD 140283 made up of?

Since the star was one of the first to be formed, it is very different to those which have formed later in the universe's life



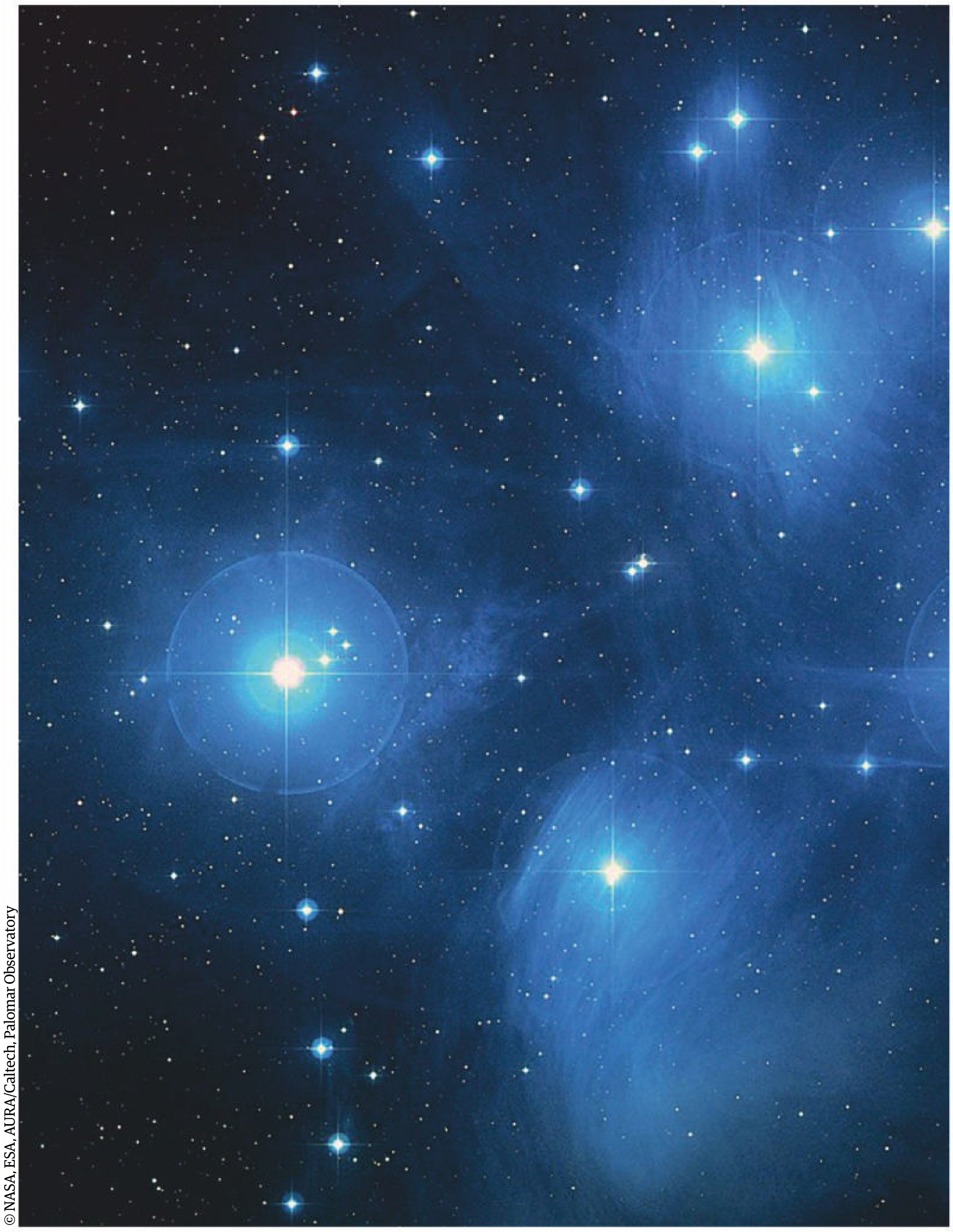
It has very little iron
The star contains just 1/250th of the iron content of our Sun, which means it had to have formed when the element was less common.

It contains more oxygen
With a high oxygen-to-iron ratio, there is evidence to suggest that it formed when the universe was abundant in oxygen very early on.

There are traces of lithium
A detectable amount of lithium within HD 140283 is due to it having not evolved into a red giant. Lithium was one of the universe's first elements to form.

Hydrogen is abundant
When astronomers used a spectrograph in order to pick up on HD 140283's signatures of elements in its light, lots of hydrogen was evident.

And so is helium
In fact, the star is pretty much entirely hydrogen and helium, and with these also the first elements to form, a reasonable idea of its age can be formulated.



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Left: Stars like those found in the Pleiades star cluster formed after the birth of the universe

was not abundant in the universe for a few million years, it pointed again to a lower age for the star. Such observations took Bond and his collaborator Professor Don VandenBerg a while to obtain, but they were able to make a breakthrough.

HD 140283's age was measured at 14.46 billion years - a significant reduction on the 16 billion previously claimed. That was, however, still more than the age of the universe itself, but the scientists posed a residual uncertainly of 800 million years, which Bond said made the star's age compatible with that of the universe, even though it wasn't entirely perfect.

"Like all measured estimates, it is subject to both random and systematic error," says physicist Professor Robert Matthews of Aston University in Birmingham, UK, speaking in a personal capacity. "The 'overlap' in the error bars gives some indication of the probability of a clash with cosmological age determinations.

He continues: "In other words, the best supported age of the star is in conflict with that for the derived age of the universe [as determined by the cosmic microwave background], and the conflict can only be resolved by pushing the error bars to their extreme limits."

Further refinements to Bond's work saw the age of HD 140283 fall further. An update in a follow-up paper by VandenBerg updated the age to 14.27 billion years. "The conclusion reached was that the age is about 14 billion years and, again, if one includes all sources of uncertainty - both in the observational measurements and the theoretical modelling - the error is about 700 or 800 million years, so there is no conflict because 13.8 billion years lies within the star's error bar."

For Bond, the similarities between the age of the universe and that of this old nearby star - both of which have been determined by different methods of analysis - is "an amazing scientific achievement which provides very strong evidence for the Big Bang picture of the universe". He says the problem with the age of the oldest stars is far less severe than it was in the 1990s when the stellar ages were approaching 18 billion years or, in one case, 20 billion years. "With the uncertainties of the determinations, the ages are now agreeing," he says.

Yet Matthews believes the problem has not yet been resolved. Astronomers at an international conference of top cosmologists at the Kavli Institute for Theoretical Physics in Santa Barbara, California, in July 2019 were puzzling over studies that suggested different ages for the universe. They were looking at measurements of galaxies that are relatively nearby which suggest the universe is younger by hundreds of millions of years compared to the age determined by the cosmic microwave background.

In fact, far from being 13.8 billion years old, as estimated by the European Planck space telescope's detailed measurements of cosmic radiation in 2013, a universe as young as 11.4 billion years is being indicated. One of those behind the studies is Nobel laureate Adam Riess of the Space Telescope Science Institute in Baltimore, Maryland. The conclusions are being based on the idea of an expanding universe, as shown in 1929 by Edwin Hubble.

This is fundamental to the Big Bang - the understanding that there was once a state of hot denseness that exploded out, stretching space. It indicates a starting point that should be measurable, but fresh findings are suggesting that the expansion rate is actually around ten per cent higher than the one suggested by Planck.

Indeed, Planck's team determined that the expansion rate was 67.4 kilometres per second per megaparsec, but measurements taken of the expansion rate of the more recent universe point to values of 73 or 74. That means there is a difference between the measurement of how fast the universe is expanding today and the predictions of how fast it should be expanding based on the physics of the early universe, Riess says. It's leading to a reassessment of accepted theories while also showing there is still much to learn about dark matter and dark energy, which are thought to be behind this conundrum.

A higher value for the Hubble Constant indicates a shorter age for the universe. A constant of 67.74 kilometres per second per megaparsec would lead to an age of 13.8 billion years, whereas one of 73 or even as high as 77 as studies have shown would indicate a universe age no greater than 12.7 billion

> "One of the uncertainties with the age of HD 140283 was the precise distance of the star" **Prof Howard Bond**

The Hubble Space Telescope has been used by astronomers to monitor and observe HD 140283

© NASA

years. It's a mismatch that suggests, once again, that HD 140283 is older than the universe. It has also since been superseded by a study which suggests a Hubble Constant of 82.4 - suggesting that the universe's age is 11.4 billion years!

Matthews believes the answers lie in greater cosmological refinement. "I suspect that the observational cosmologists have missed something that creates this paradox, rather than the stellar astrophysicists," he says, pointing to the measurements of the stars being perhaps more accurate. "That's not because the cosmologists are in any way sloppier, but because age determination of the universe is subject to more and arguably trickier observational and theoretical uncertainties than that of stars."

He says unknown systematic biases which make the true value lie even outside the error bars are always possible, but that these seem less likely in the case of stellar ages than the possibility that the cosmological age is misleading in some way.

But what could be making the universe potentially appear younger than this particular star? "There are two options, and the history of science suggests that in such cases the reality is a mix of both," he offers. "In this case that would be sources of observational error that haven't been fully understood, plus some gaps in the theory of the dynamics of the universe, such as the strength of dark energy, which has been the prime driver of the cosmic expansion for many billions of years now."

Indeed, he suggests the possibility that the current 'age paradox' reflects time variation in dark energy, and thus a change in the rate of acceleration - a possibility theorists have found might be compatible with ideas about the fundamental nature of gravity, such as so-called causal set theory. He also says new research into gravitational waves could help to resolve the paradox. "Analysis of gravitational waves provides a new, independent and potentially 'cleaner' way of measuring the Hubble Constant, and thus the age of the universe," Matthews adds.

To do this, scientists would look at the ripples in the fabric of space and time created by pairs of dead stars, rather than relying on the cosmic microwave background or the monitoring of nearby objects such as Cepheid variables and supernovae to measure the Hubble Constant - the former resulting in the speed of 67 kilometres per second per megaparsec and the latter in 73.

Trouble is, measuring gravitational waves is no easy task, given they were only directly detected for the first time in 2015. But according to Stephen Feeney, an astrophysicist at the Flatiron Institute in New York, a breakthrough could be made over the course of the next decade. The idea is to collect data from collisions between pairs of neutron stars using the visible light these events emit to figure out the speed they are moving relative to Earth. It also entails analysing the resulting gravitational waves for an idea of distance - both of which can combine to give a measurement of the Hubble Constant that should be the most accurate yet.

The mystery of the age of HD 140283 is leading to something bigger and more scientifically complex, altering the understanding of how the universe works. At the same time, work on ageing the universe is ongoing with, Matthews has argued, a need to reassess some unreliable assumptions that have been used to estimate the distances to far-away galaxies. "The most likely explanations for the paradox are some overlooked observational effect and/or something big missing from our understanding of the dynamics of the cosmic expansion," he says. Precisely what that 'something' is, is sure to keep astronomers challenged for some time.

Above: Scientists have been keen to discover when the universe began - that is, when the Big Bang occurred and left its imprint on the fabric of the cosmos

Left: Riess says the universe is expanding ten per cent faster than predicted by observations of the universe's trajectory shortly after the Big Bang - a larger constant indicates a faster moving and younger universe

The theories

Just why is the star seemingly older than the universe?

The star really did come first

Maybe, just maybe, this star was around before the Big Bang and somehow got caught up in our universe as it was forming. One thing we do know is that its make-up points to HD 140283 being of around the same vintage as the universe, making it a close-run thing.

The universe's age is wrong

It's rather implausible to suggest that a star is older than the universe, and you'd be hard-pressed to find a scientist who believes that's the case. The smart money is therefore on the current dating of universe at 13.8 billion years being incorrect, which means more studies are needed.

The dating of the star is wrong

Given the fact the star's age has been revised downwards over the past few decades, there is every chance that it needs greater refinement. It currently stands at 14.27 billion years, give or take 800 million years, but what if the star is confirmed to be younger? The work is ongoing.

> "Age determination of the universe is subject to trickier observational and theoretical uncertainties" **Prof Robert Matthews**

VENUS' WILD CLIMATE SHIFTS

Long billed as Earth's much hotter twin, many mysteries hide within the thick envelope of clouds that surround the planet - and these may also be responsible for its dramatic atmospheric changes

A new study on a decade of ultraviolet observations of Venus from 2006 to 2017 showed that the planet's reflection of ultraviolet light decreased by half before shooting back up again, researchers said. This change resulted in large variations in the amount of solar energy absorbed by Venus' clouds and the circulation in its atmosphere, causing the changes in the planet's climate, they added.

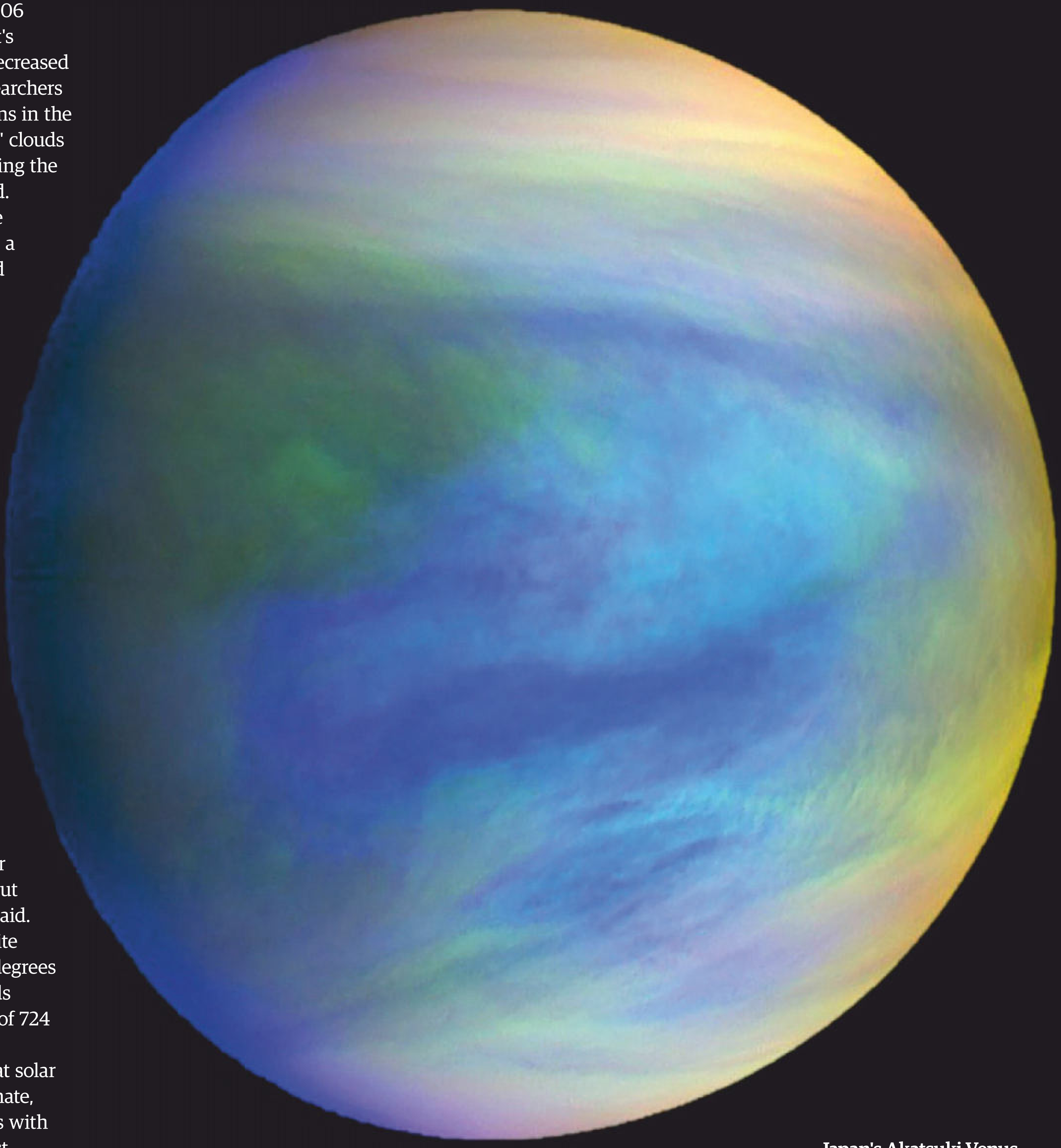
"Current climate changes on Venus have not been considered before," Yeon Joo Lee, a researcher at the Center for Astronomy and Astrophysics at the Technical University of Berlin and lead author of the study, told **space.com**. "Moreover, the level of UV-albedo [reflectivity] variations is significantly large, so sufficient to affect atmospheric dynamics."

The weather on Venus, like that of the Earth, is affected by solar radiation and the changes in the reflection of its surrounding clouds. Unlike Earth, Venus' clouds are made up of sulphuric acid and contain dark patches that scientists refer to as 'unknown absorbers', as they absorb most of the heat and ultraviolet light emitted by the Sun. The new study suggests that these absorbers may be what is causing these changes in Venus' climate, although the team of scientists believe that the only way to know for sure is through further observations.

"At least one more decade [of] observation. That will cover one more solar activity cycle, and we will be able to find out whether or not this change is cyclic," Lee said.

The weather on the planet is already quite extreme, with temperatures reaching 471 degrees Celsius (880 degrees Fahrenheit) and winds sweeping across Venus' surface at a speed of 724 kilometres (450 miles) per hour.

If further observations were to prove that solar activity is connected to this change in climate, then it could be applied to all other planets with aerosols, solid or liquid particles that reflect sunlight, such as Earth and Titan, according to Lee. However, the degree of change would be different in each one.



Japan's Akatsuki Venus orbiter, NASA's Messenger spacecraft and Hubble observed Venus for the study

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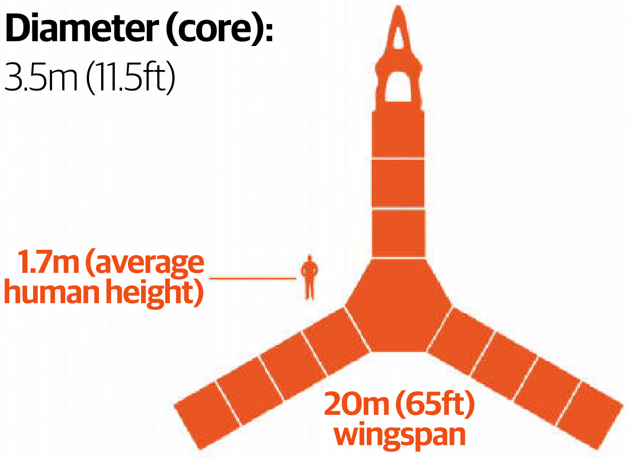
USER MANUAL

Juno spacecraft

THE SPECS

Launch: 5 August 2011
Launch rocket: Atlas V 551
Target: Jupiter
Operators: NASA JPL
Programme cost: $1.1bn (£760mn)
Components: Multiple components
Height (core): 3.5m (11.5ft)
Diameter (core): 3.5m (11.5ft)



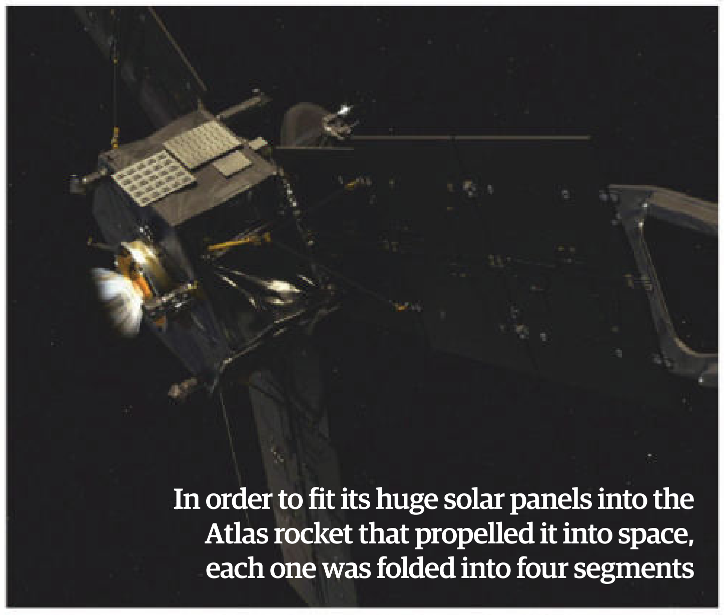
For NASA and its Jet Propulsion Laboratory, the Jupiter Near-Polar Orbiter (Juno) is more than just another analytical study far out in the depths of space - it's a step forwards for alternative fuels in deep space travel and could very well change the way we design such craft in the decades to come.

Interestingly, the estimated $1.1 billion (£760 million) programme isn't the first NASA effort to study the imposing gas giant sitting far across the expanse of our Solar System. From 1995 to 2003, the proverbial 'old faithful' Galileo probe was held in Jovian orbit for a staggering eight years before eventually being deorbited and torn apart in the gas giant's turbulent atmosphere. Galileo revealed a treasure trove of information about the largest planet in our corner of space, including the theory of a liquid ocean, as well as providing a greater understanding of how its unique magnetosphere conducts itself around the chaos of its composition. So what has Juno been doing since it entered Jovian orbit in July 2016? The craft has been studying the planet in incredible detail in an attempt to understand the true nature of the Solar System's most violent planet.

Juno is investigating the core mass of the planet in the hope of better understanding how such an object formed in the furnace of our Solar System's creation, while also studying the ratio of oxygen to hydrogen - another area that could share more insight into that early formation era. The planet's

> "Juno is investigating the core mass of Jupiter in the hope of understanding how such an object formed"

Juno was tested in a thermal vacuum chamber to simulate the harsh space environments the probe will encounter

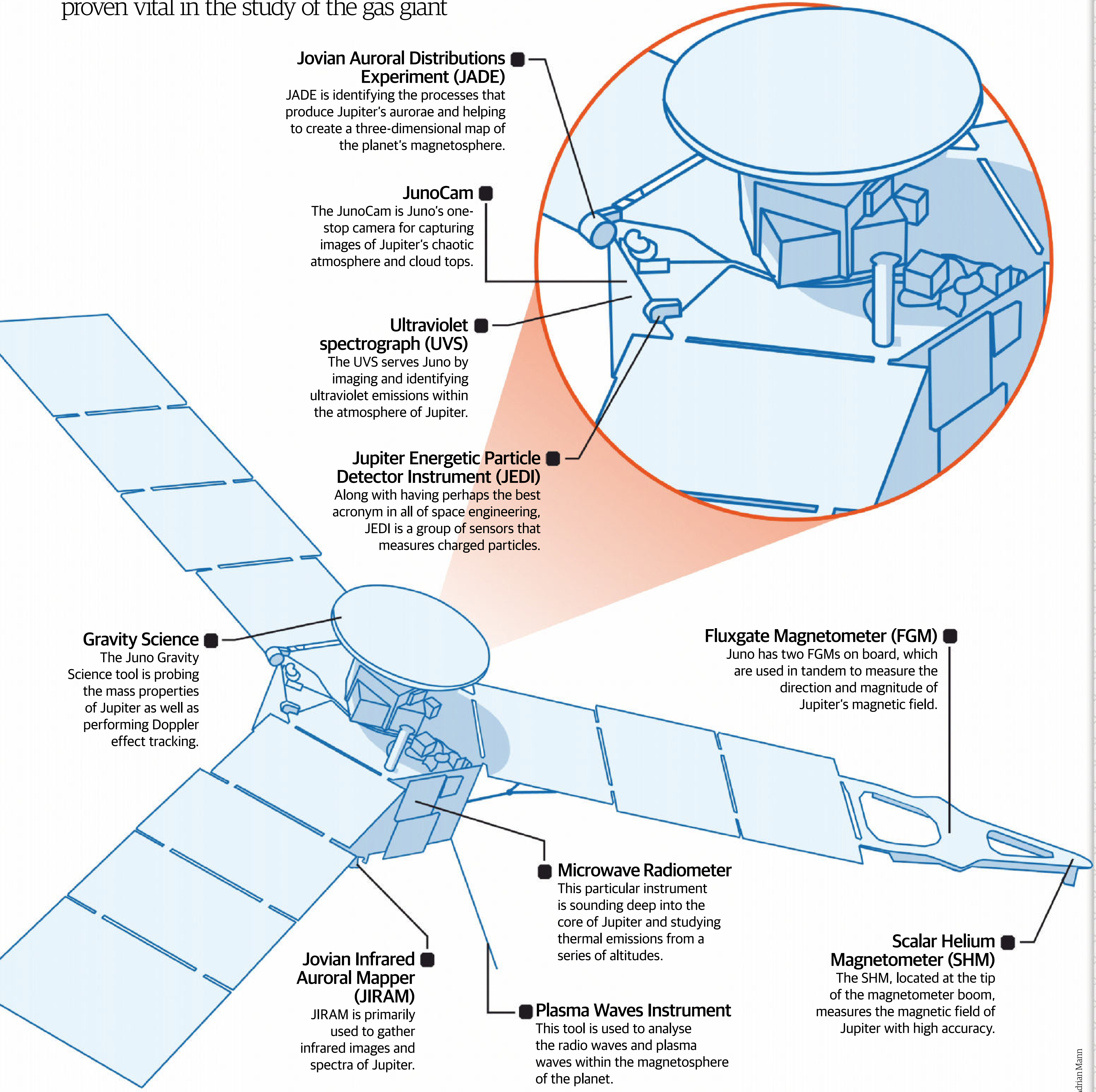


In order to fit its huge solar panels into the Atlas rocket that propelled it into space, each one was folded into four segments

A technician inspects one of Juno's insulating blankets before it is installed on the Magnetometer

Anatomy of Juno

Its instruments may not be revolutionary, but they have proven vital in the study of the gas giant



Jovian Auroral Distributions Experiment (JADE)
JADE is identifying the processes that produce Jupiter's aurorae and helping to create a three-dimensional map of the planet's magnetosphere.

JunoCam
The JunoCam is Juno's one-stop camera for capturing images of Jupiter's chaotic atmosphere and cloud tops.

Ultraviolet spectrograph (UVS)
The UVS serves Juno by imaging and identifying ultraviolet emissions within the atmosphere of Jupiter.

Jupiter Energetic Particle Detector Instrument (JEDI)
Along with having perhaps the best acronym in all of space engineering, JEDI is a group of sensors that measures charged particles.

Gravity Science
The Juno Gravity Science tool is probing the mass properties of Jupiter as well as performing Doppler effect tracking.

Fluxgate Magnetometer (FGM)
Juno has two FGMs on board, which are used in tandem to measure the direction and magnitude of Jupiter's magnetic field.

Microwave Radiometer
This particular instrument is sounding deep into the core of Jupiter and studying thermal emissions from a series of altitudes.

Jovian Infrared Auroral Mapper (JIRAM)
JIRAM is primarily used to gather infrared images and spectra of Jupiter.

Plasma Waves Instrument
This tool is used to analyse the radio waves and plasma waves within the magnetosphere of the planet.

Scalar Helium Magnetometer (SHM)
The SHM, located at the tip of the magnetometer boom, measures the magnetic field of Jupiter with high accuracy.

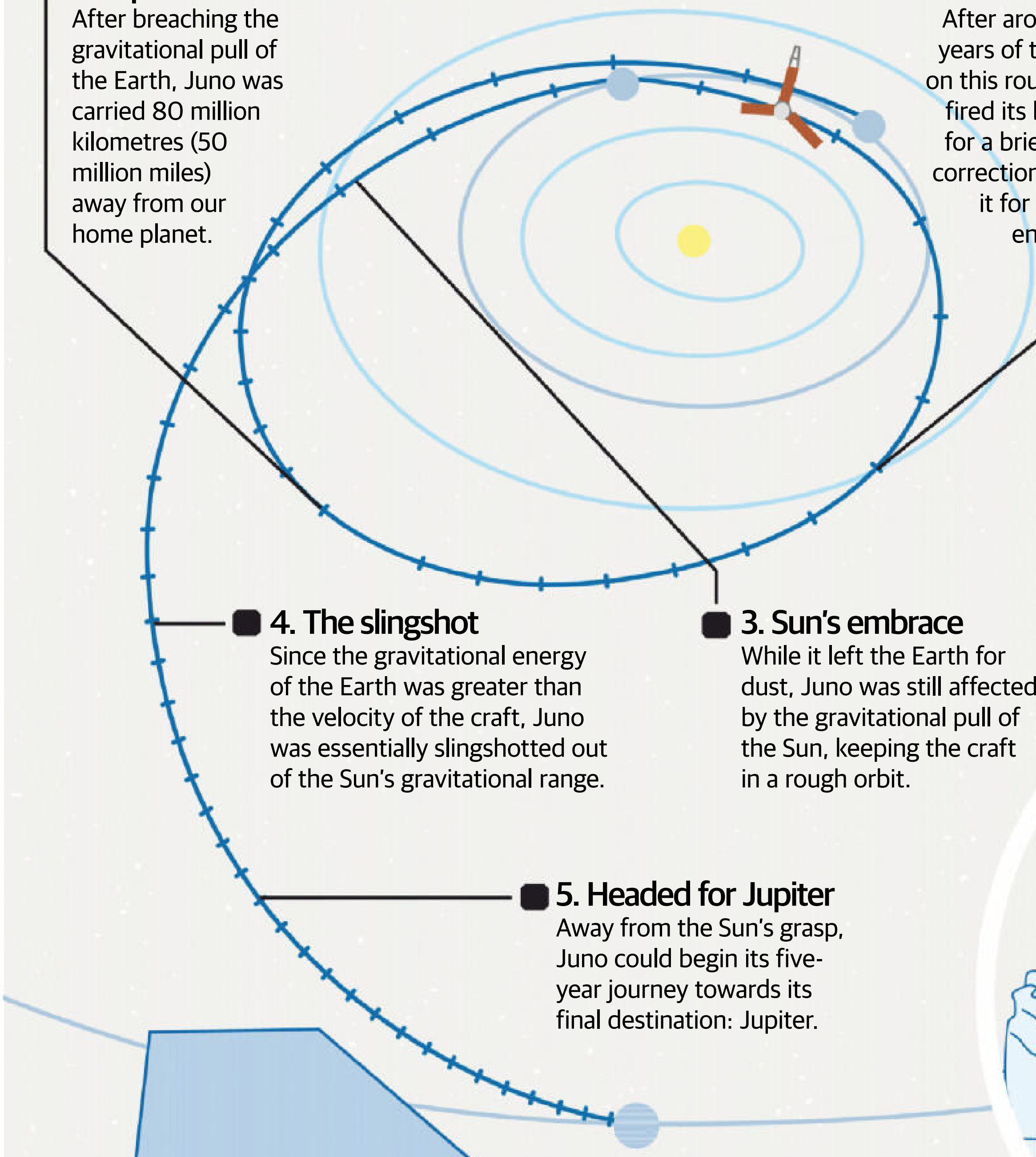
© Adrian Mann

magnetic and gravitational fields are also of great interest to NASA - Juno is studying the depth of Jupiter's gravitational pull to the dynamics of its deep core, as well as tracking its magnetic field to see just how far into the planet such a process originates. This study is also bringing us a little closer to understanding the wider effect of the dynamo theory, the process whereby a celestial body creates a magnetic field.

That's not it for Juno either - NASA will construct a three-dimensional picture of Jupiter's magnetosphere for the first time, following on from the data collected by Galileo more than a decade ago. There are even plans to apply Einstein's general theory of relativity to Jovian rotation, as well as further tests to study the planet's temperature. It's a pretty tall order, even for the biggest of spacecraft, but it's got plenty of established technology up its sleeve to get the Jovian job done.

The craft is undertaking a rather unusual orbit - a highly elliptical polar orbit to be precise - which was chosen specifically to help Juno avoid most of Jupiter's highly radioactive regions. Since radiation levels are still incredibly high, even in the comparatively safer band between the poles, Juno keeps its most vital electronics within a radiation-shielded vault. This vault

How Juno performed a gravity assist manoeuvre



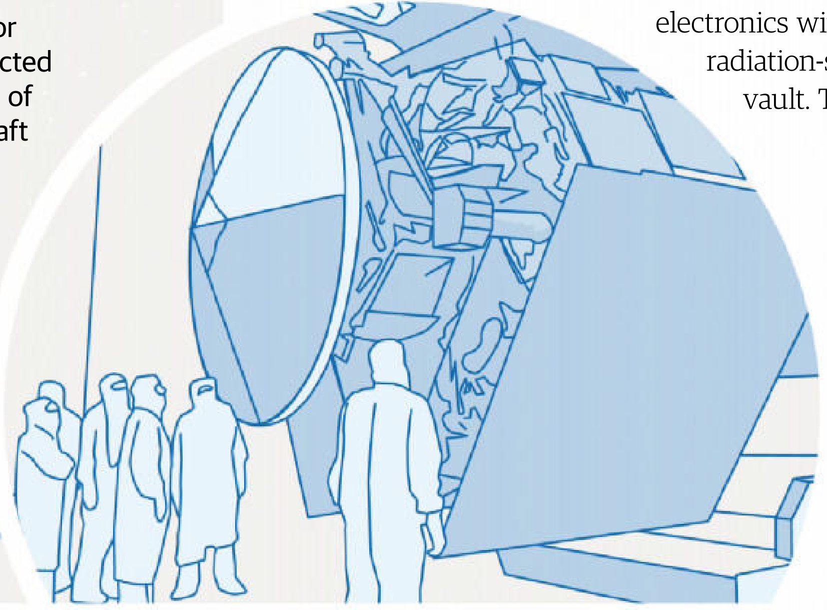
1. Getting into position
After breaching the gravitational pull of the Earth, Juno was carried 80 million kilometres (50 million miles) away from our home planet.

2. Course correction
After around two years of travelling on this route, Juno fired its boosters for a brief course correction to align it for an Earth encounter.

3. Sun's embrace
While it left the Earth for dust, Juno was still affected by the gravitational pull of the Sun, keeping the craft in a rough orbit.

4. The slingshot
Since the gravitational energy of the Earth was greater than the velocity of the craft, Juno was essentially slingshotted out of the Sun's gravitational range.

5. Headed for Jupiter
Away from the Sun's grasp, Juno could begin its five-year journey towards its final destination: Jupiter.



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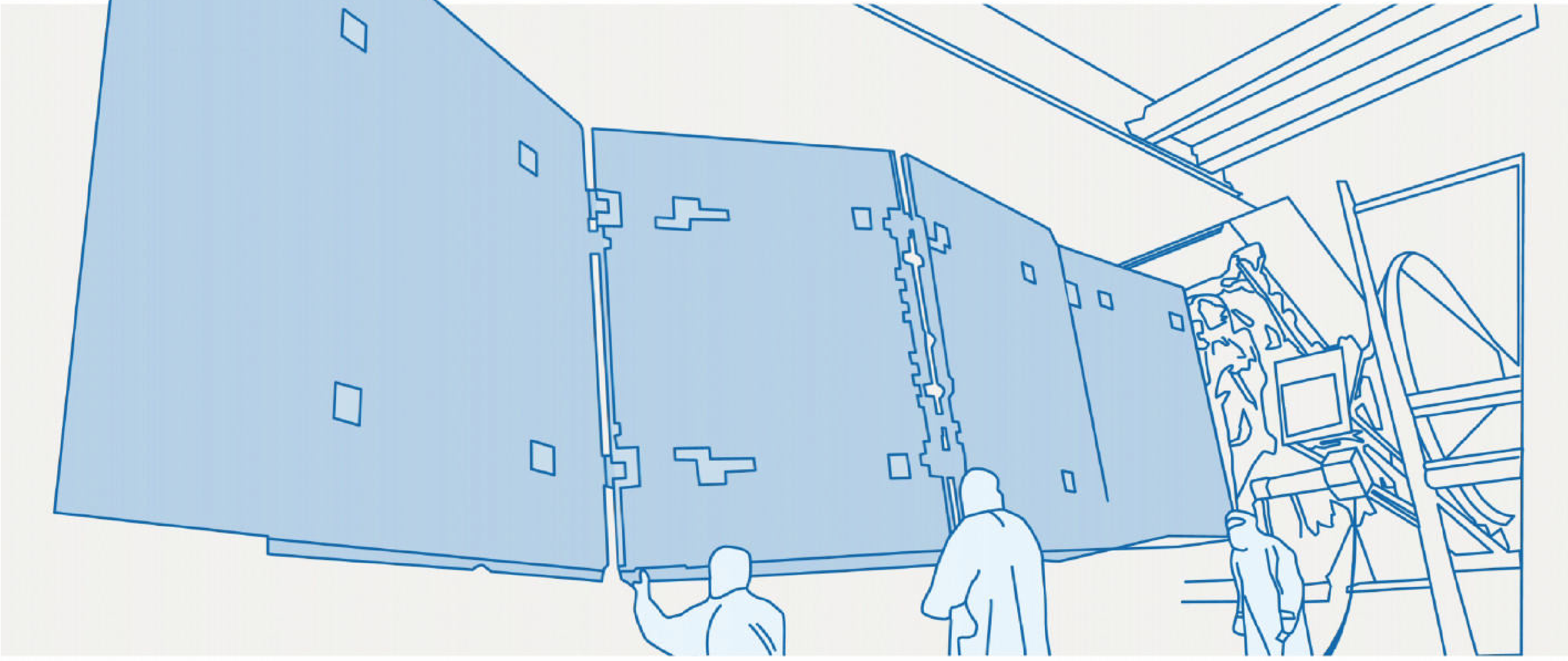


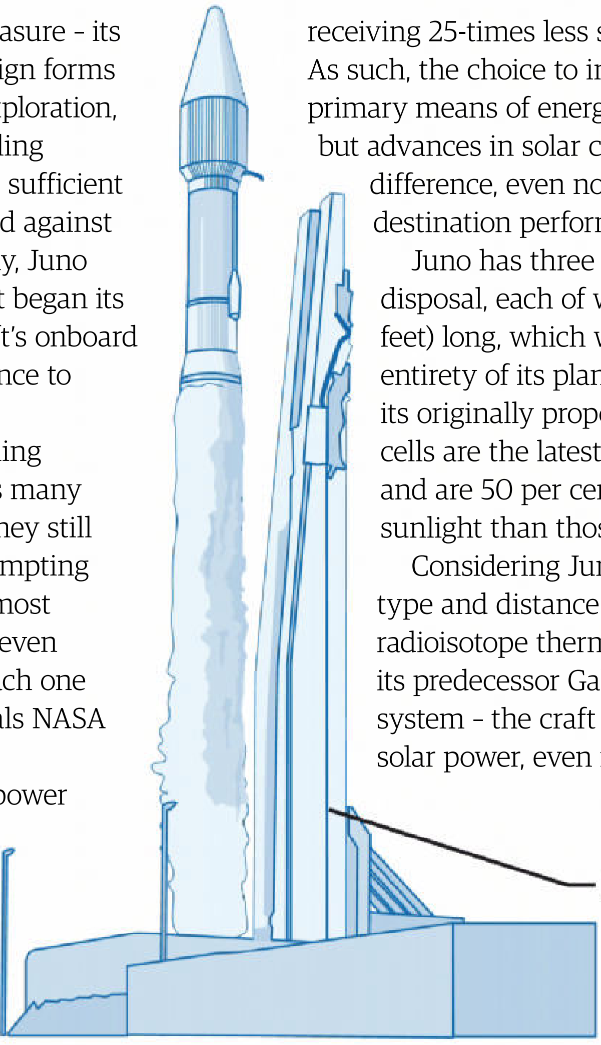
wasn't thrown in just for good measure - its inclusion in the primary Juno design forms part of NASA's Vision for Space Exploration, which states any spacecraft travelling beyond low-Earth orbit must have sufficient radiation shielding in order to ward against failure out in the field. Interestingly, Juno was also in perpetual spin when it began its orbit, a procedure vital for the craft's onboard instruments to have an equal chance to study the planet in depth.

Those instruments aren't anything new to those familiar with NASA's many other probes and spacecraft, but they still prove vital on board a vehicle attempting to unlock some of the universe's most unusual secrets. Juno is packing seven main instruments in total, with each one facilitating those all-important goals NASA has planned.

However, it's in its use of solar power that Juno is making its biggest waves. At a distance of 588 million kilometres (365 million miles) - that's five-times the distance between the Earth and the Sun - Juno will be receiving 25-times less sunlight than we do here. As such, the choice to include solar panels as the primary means of energy may seem a little reductive, but advances in solar cell design are making all the difference, even now as it hurtles around its destination performing its science.

Juno has three large solar panels at its disposal, each of which is 8.9 metres (29.2 feet) long, which will power the craft for the entirety of its planned mission, now well past its originally proposed two-year lifespan. Those cells are the latest in solar power technology and are 50 per cent more effective at utilising sunlight than those used in previous missions.

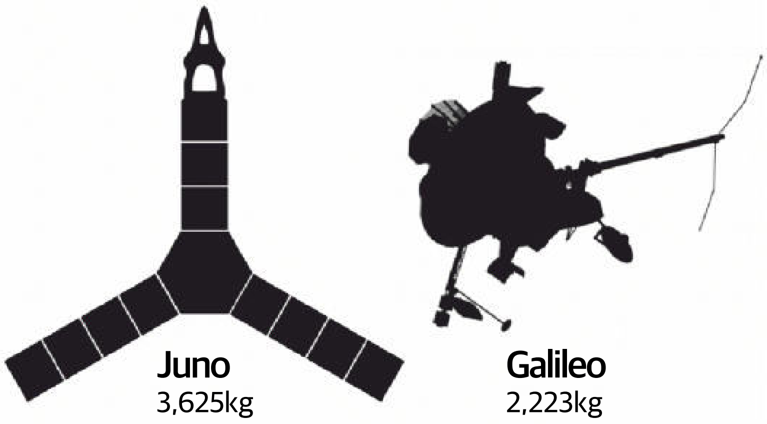
Considering Juno is the first mission of this type and distance to not utilise traditional radioisotope thermoelectric generators - even its predecessor Galileo used such a propulsion system - the craft is proving the potential of solar power, even in the deepest of space.



Atlas V 551 rocket
The space rocket launched Juno on its five-year journey from Cape Canaveral, Florida.

Head to head

When it comes to size, Juno outshines the previous Jupiter craft, Galileo, as its three solar panels give the craft a 20-metre (65-foot) wingspan. In terms of weight Juno also has the edge, with an impressive 3,625 kilogram (8,000 pound) launch mass - for comparison, a double-decker bus weighs 12,000 kilograms (26,460 pounds). In terms of time, Galileo took six years to reach Jupiter, while Juno made the trip in less than five.



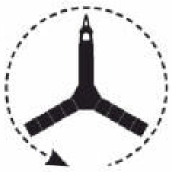
TOP TECH

Solar panels:
the tech changing deep space travel forever

In January 2016, Juno became the most distant solar-powered craft from the Sun. The record was previously held by the ESA's Rosetta probe. With 18,698 solar cells at its disposal, spread over three panels, Juno has more than enough energy to power its mission. At Earth distance those silicon and gallium arsenide cells generate 14kW of energy, but that was much lower when it arrived at Jupiter.

Vital statistics

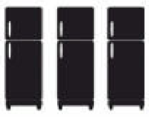
2 hours The time it takes Juno to fly from pole to pole = It will spin **400** times during this period



486 watts The power generated by Juno when it arrived at Jupiter = The same as eight 60W bulbs

3.5m The height of Juno = That's slightly taller than a basketball hoop

340kg The combined weight of all three panels = Roughly the same as three fridges



620km/h Top speed of solar winds around Jupiter = Over three-times faster than a family hatchback

HOW TO...

Get a spacecraft into an orbit

1 The big launch

On 5 August 2011, Juno lifts off from Cape Canaveral aboard an Atlas V 551 rocket. After one minute and 33 seconds, the two main boosters detach and fall away. The main engine falls away at four minutes and 26 seconds, and after just 40 minutes Juno is out of Earth orbit.

2 Earth flyby

Two years later, the Juno spacecraft performs an Earth flyby on 9 October 2013. This gives the craft the large speed boost it needs to reach Jovian space. The flyby brings the craft within 559 kilometres (347 miles) of Earth before flinging it back out into deep space.

3 Entering Jovian orbit

On 5 July 2016, Juno approached Jupiter and began an orbital insertion burn in order to slow its speed and enable the craft to enter a highly elliptical 53-day orbit around the planet. The craft then began its mission, and has so far completed over 20 orbits.

4 End of mission

After 24 months, NASA planned to terminate Juno by removing it from elliptical orbit and manoeuvring it into the planet's turbulent atmosphere, where it would burn up. However, the Juno mission has been extended to at least July 2021.

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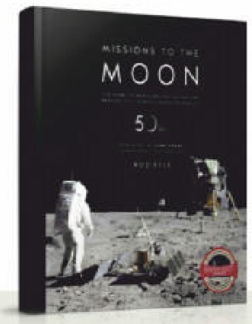

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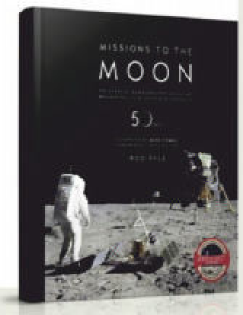

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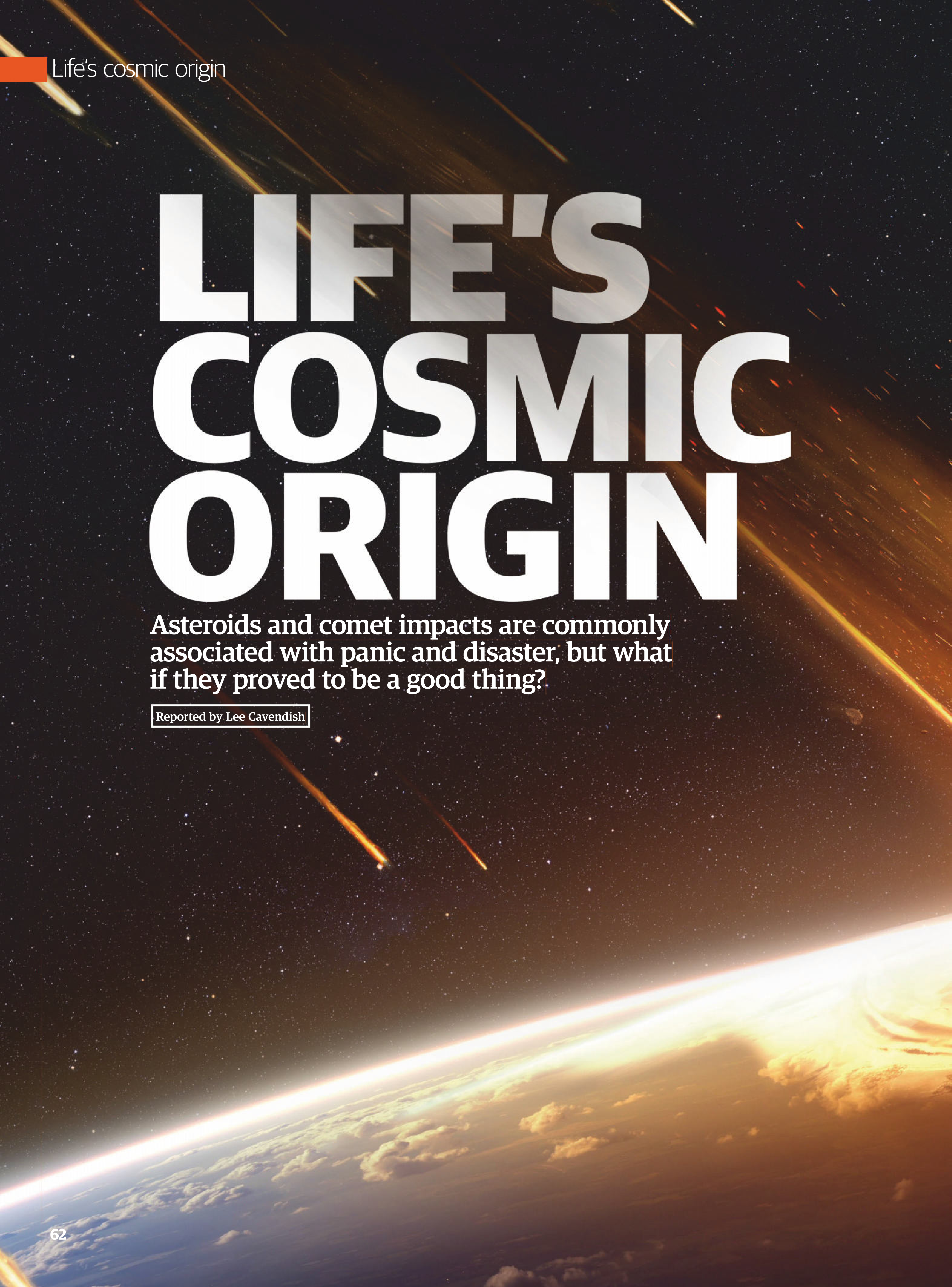


LIFE'S COSMIC ORIGIN

Asteroids and comet impacts are commonly associated with panic and disaster, but what if they proved to be a good thing?

Reported by Lee Cavendish

The most fundamental and philosophical mystery around has got to surround where life came from. It is one thing to discuss how life grew from a single-cell organism to this global presence of intelligent life, but to then ask how the first single-cell organism arrived in the first place further complicates things. Here we'll explore one possibility, the introduction of the ingredients via asteroids and comets.

Let's examine the timeline based on known facts about the Solar System and Earth. The Sun, the planets and all the comets and asteroids scattered across the Solar System came into existence roughly 4.5 billion years ago, 9.3 billion years after the formation of the universe. 4.2 billion years ago, water was able to condense on Earth in the Solar System's habitable zone - the distance from the Sun where temperatures allow liquid water to exist. Then, 3.7 billion years ago, the oldest-known form of life was present on Earth in the form of cyanobacteria known as stromatolites.

Evidence for this was found in southwestern Greenland, showing the oldest trace of living organisms on Earth. Within this 500 million year period between water condensing and the presence of stromatolites, life began. Unfortunately, due to the rapidly changing nature of Earth's surface in these prehistoric times, it's almost impossible

© Tobias Roetsch

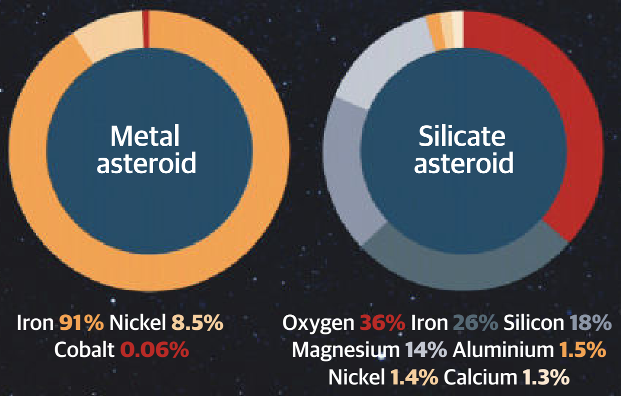
Asteroids vs comets

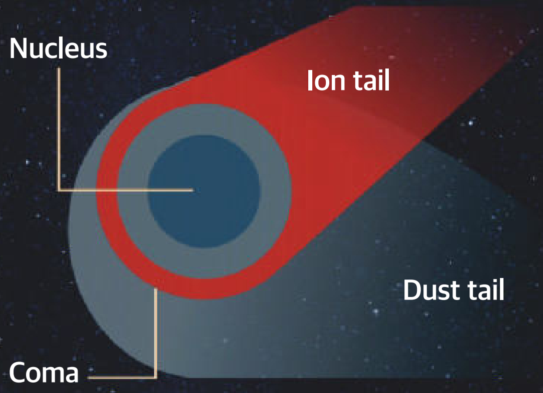
These two time capsules of the Solar System could hold the answers to the life-long question of humanity's origin

IDENTIFICATION

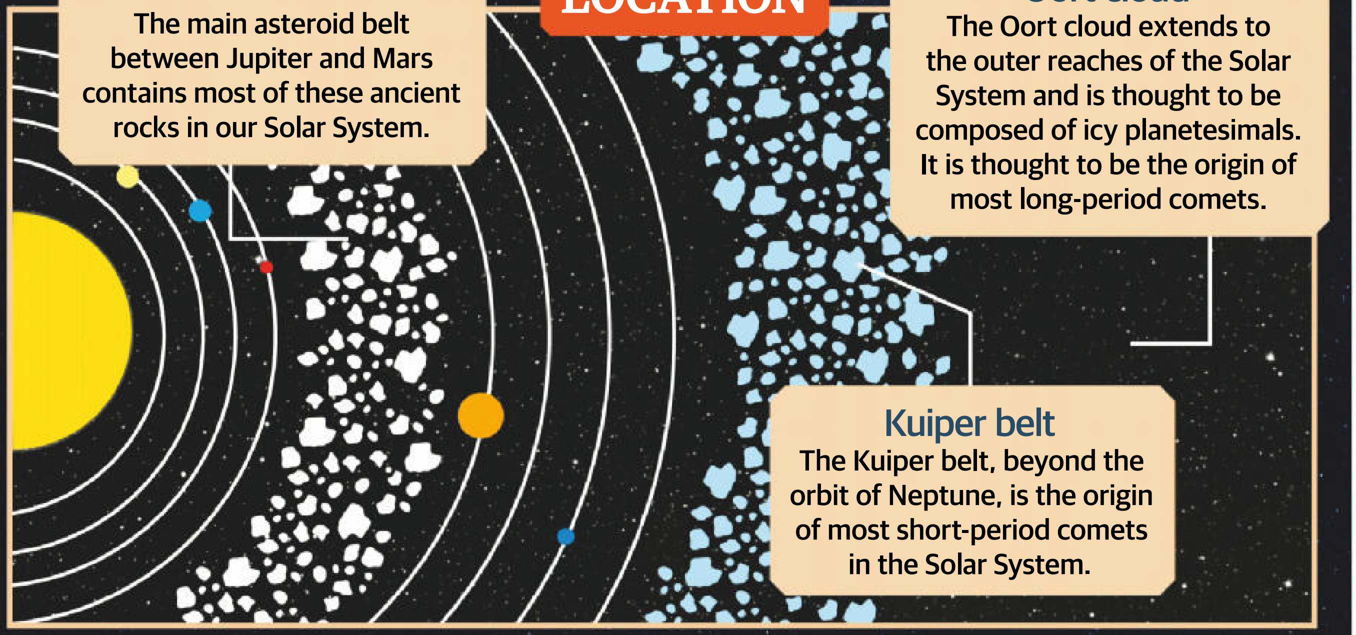
Asteroids
These types of space rocks are composed primarily of silicates, metals or a combination of the two.

Comets
Comets mainly contain ices with smaller amounts of rock and dust. They form a coma and a tail.





LOCATION

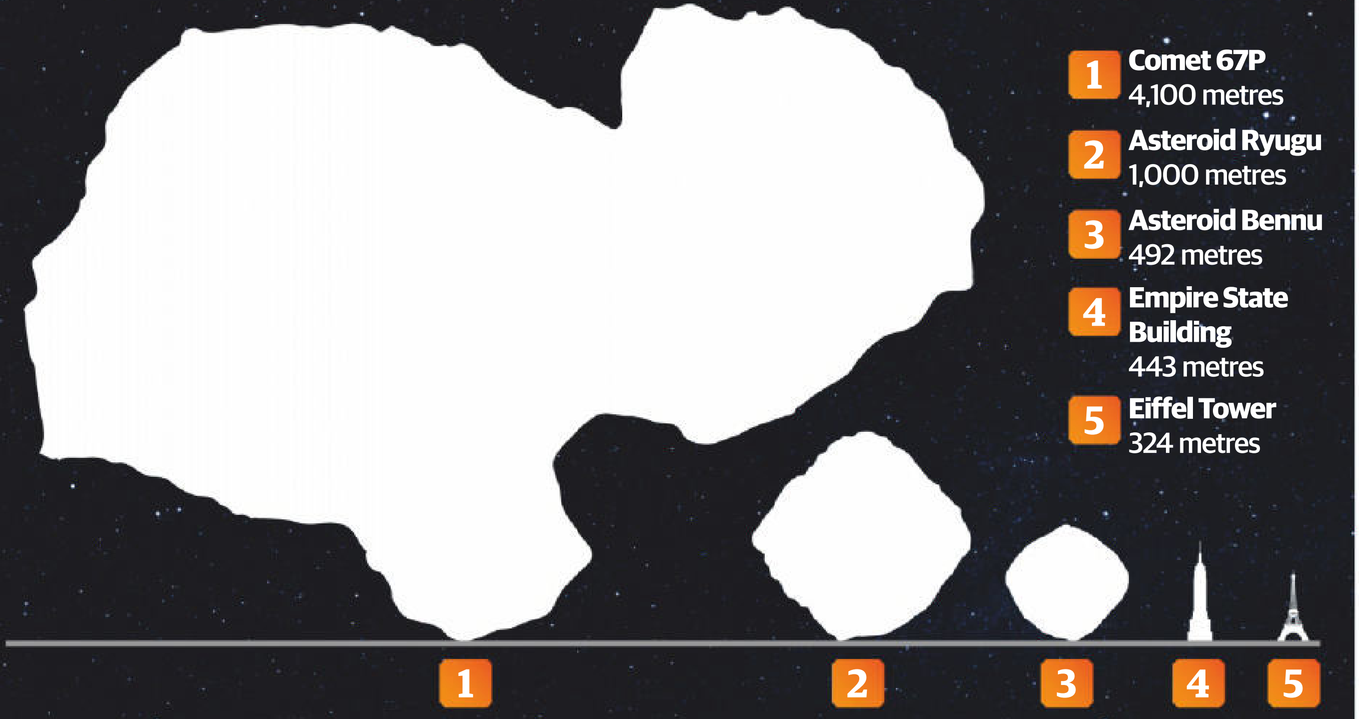


Main asteroid belt
The main asteroid belt between Jupiter and Mars contains most of these ancient rocks in our Solar System.

Oort cloud
The Oort cloud extends to the outer reaches of the Solar System and is thought to be composed of icy planetesimals. It is thought to be the origin of most long-period comets.

Kuiper belt
The Kuiper belt, beyond the orbit of Neptune, is the origin of most short-period comets in the Solar System.

PUTTING IT INTO PERSPECTIVE



1 **Comet 67P** 4,100 metres
2 **Asteroid Ryugu** 1,000 metres
3 **Asteroid Bennu** 492 metres
4 **Empire State Building** 443 metres
5 **Eiffel Tower** 324 metres

to denote a definitive start point. One option that definitely warrants further investigation, however, is the introduction of life, if not the ingredients for life, hitchhiking on comets and asteroids.

"The question of what most likely [created life on Earth] depends on how easy it is for us to reproduce the conditions that took place on Earth in the laboratory. There are several groups trying to do that - one of them is at Harvard," says Avi Loeb, Frank B. Baird Jr. Professor of Science at Harvard University in Cambridge, Massachusetts, to **All About Space**. "Jack Szostak - he's the leader of that group - when he started doing the experiments, he thought that creating life out of random processes on the early Earth, it must be very unlikely because of the complexity of time. But now, after several years of working on it, he is pretty much convinced that random processes on Earth could have led to what we see. He's not of the opinion that it was necessary to bring life to Earth from outside."

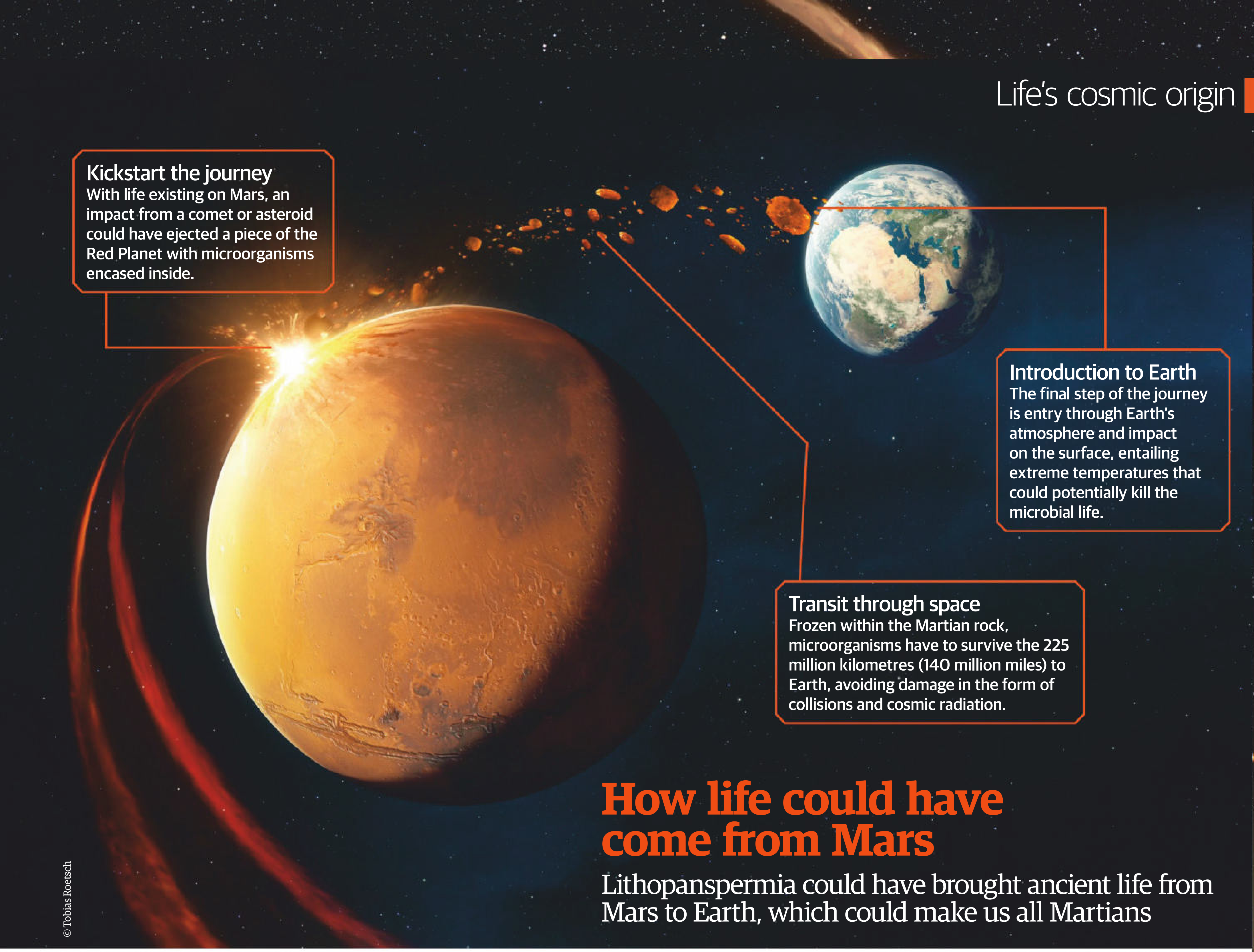
That is currently the leading idea, confirmed to us here by one of the world's most qualified astronomers, that life was built from the ground up and that aliens from a galaxy far, far away did not gift us with life. However, this is still just a theory, and there is still the question of how Earth got its complex organic compounds and oceans of water to blend these ingredients together.

Asteroids and comets have been the target of several space exploration missions in recent times, with three of the world's grandest space agencies executing robotic missions to visit them. NASA has the Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-REx) mission at the asteroid Bennu; the Japan Aerospace Exploration Agency's (JAXA) Hayabusa2 mission is at the asteroid Ryugu and the European Space Agency's (ESA) Rosetta-Philae mission visited the comet 67P/Churyumov-Gerasimenko.

The last of these three, Rosetta at Comet 67P, has revealed some exciting results about the

How life could have come from Mars

Lithopanspermia could have brought ancient life from Mars to Earth, which could make us all Martians



Kickstart the journey
With life existing on Mars, an impact from a comet or asteroid could have ejected a piece of the Red Planet with microorganisms encased inside.

Introduction to Earth
The final step of the journey is entry through Earth's atmosphere and impact on the surface, entailing extreme temperatures that could potentially kill the microbial life.

Transit through space
Frozen within the Martian rock, microorganisms have to survive the 225 million kilometres (140 million miles) to Earth, avoiding damage in the form of collisions and cosmic radiation.

© Tobias Roetsch

Below: Meteors could have brought cyanide, a compound that could power bacteria

© NASA's Goddard Space Flight Center Conceptual Image Lab

chemistry residing within these dusty snowballs. "The particular type of water found on Comet 67P does not match that of Earth's oceans today, but other comets created elsewhere in our Solar System may provide better matches," says Douglas Vakoch, president of Messaging Extraterrestrial Intelligence International (METI) and an astrobiologist, to **All About Space**. "This one example of the European Space Agency's mission to a comet reminds us that a successful expedition may yield as many new questions as answers."

Although this mission didn't find conclusive evidence that comets are the true water bearers that gave the Earth its oceans, it is still the most widely accepted theory. Hopefully with more missions to the hundreds of thousands of comets scattered around the Solar System, astrobiologists will find water buried within a comet that does match the signal of Earth's water. However, the Rosetta mission did yield much more positive results for complex molecules. "The mission also helped us understand the specific organic compounds present on this comet, including the amino acid glycine. Even if comets didn't seed early Earth with full-blown life, they may have contributed organic material, as well as water," continues Vakoch.

But just what is glycine, and why is it important? Well, glycine is an amino acid which is basically a building block for life as we know it. Amino acids make up protein, one of the most crucial compounds that humans need to live and grow, and this was found on a comet hundreds of thousands of miles away.

The other two asteroid missions, which at the time of writing are still in orbit and functioning around their respective asteroids, conducting amazing scientific experiments, are both planned to perform a sample collection and delivery back to Earth, a feat that has never been accomplished before. What makes asteroids so special, warranting this kind of grab-and-go mission in space, is that they are essentially frozen time capsules from when the planets were born. Whereas Earth, Mars and every other planet in the Solar System has undergone drastic surface changes throughout the last billions of years, essentially destroying any evidence of past life, asteroids could still have signs of the ancient, life-giving organic molecules shielded from the cosmic rays and preserved in the freezing vacuum of space.

JAXA's Hayabusa2 has yet to announce any groundbreaking scientific discoveries, but these will likely come after the sample delivery. It collected a

> "The particular type of water found on Comet 67P does not match that of Earth's oceans" **Douglas Vakoch**

sample of Ryugu on 11 July 2019 and will return it safely to Earth in 2020, depositing it in the outback desert of southern Australia. NASA's OSIRIS-REx mission, on the other hand, will collect a sample of Bennu in mid-2020 and return it to Earth in 2023. This sample collection may arrive well after JAXA's, but scientific gains have already come from this mission, with scientists at NASA and Boise State University in Idaho stating that compounds such as carbon monoxide and cyanide can be found on carbon-rich asteroids such as Bennu.

When people think of cyanide, they will most likely think of the poisonous, suffocating gas. However, to scientists studying meteorite samples, signs of this compound mean it could have powered bacteria and archaea billions of years ago, in a time when collisions between Earth and these asteroids were much more frequent. Sadly these astronomers will have to wait until 2023 to confirm or deny such theories.

Another theory is panspermia, which is the idea that life was brought to Earth from outer space. A sub-theory of this is lithopanspermia, the idea that microorganisms were ejected from a host planet after an impact of some sort, preserved as they travelled through freezing space and then making their way to Earth, surviving the atmospheric entry and impact. "Microorganisms that travel from one planet to another inside rocks ejected after comet or asteroid impacts have a dangerous journey to another planet. First they need to survive ejection. Then they need to survive their travel to another planet, which could take millions of years or more. And then they need to withstand the heat of passing through the atmosphere of their adopted world, and survive the impact. The relative risks of each phase depends in part on the nature of the star system where the interplanetary travel occurs," explains Vakoch. "For example, the TRAPPIST-1 system is centred around a dim, red dwarf star, with at least three planets tightly packed into the star's habitable zone. The proximity of these planets to one another could radically reduce the travel time of ejected material from one planet to another, making it potentially easier for life to survive that phase of the journey."

With less travel time, there is a lower possibility of things going wrong in transit. So what could have brought life to Earth? Perhaps Mars? "It's possible. While Mars had an atmosphere, it had liquid water and life emerged on Mars, even before it did on Earth. We did have Martian rocks that were kicked out of Mars and arrived to Earth, one of which was not heated by more than 40 degrees Celsius [104 degrees Fahrenheit] inside its deep interior, and we know that from the magnetic patterns," explains Loeb. "And so, such a rock could have delivered early life from Mars to Earth, so we don't actually know if we are all Martians, or not."

SA Wiki

Right: Stromatolites are rock-like structures that formed from ancient bacteria

© GFDL

Trio of space rock explorers

The spacecraft are on the hunt for primordial building blocks, including ice and complex organic molecules

	1 Rosetta	2 OSIRIS-REx	3 Hayabusa2
Operator	European Space Agency	NASA	JAXA
Destination	67P/Churyumov-Gerasimenko	101955 Bennu	162173 Ryugu
Date of arrival	6 August 2014	3 December 2018	27 June 2018
Sample collection?	No	Yes, return due 2023	Yes, return due 2020
Any signs of water?	Yes, but not like Earth's	Not yet	Not yet
Any signs of complex molecules?	Yes, glycine	Potentially cyanide and carbon monoxide	Not yet

© JAXA

© NASA/Villanueva/Mumma/Gallagher/Feimer et al

This would not be an invasion, but Martian rocks raining from above, delivering its prehistoric life from before it lost its atmosphere completely and lost its life as a result. Results that lend credibility to such an argument come at the hands of NASA's Mars Atmosphere and Volatile Evolution (MAVEN) spacecraft, which suggest that Mars lost its atmosphere around 3.7 billion years ago. Before this Mars had lakes of flowing water and most likely its own microbial life, but then the Red Planet lost its atmosphere to space – thus losing the protective blanket that kept its hospitable conditions. Now it is just the dry, barren land that is seen today by numerous orbiters and rovers. However, based on this timeline and the evidence shown by Martian meteorites found on Earth, it is not out of the realms of possibility to suggest that life on Earth could have arisen from life on Mars.

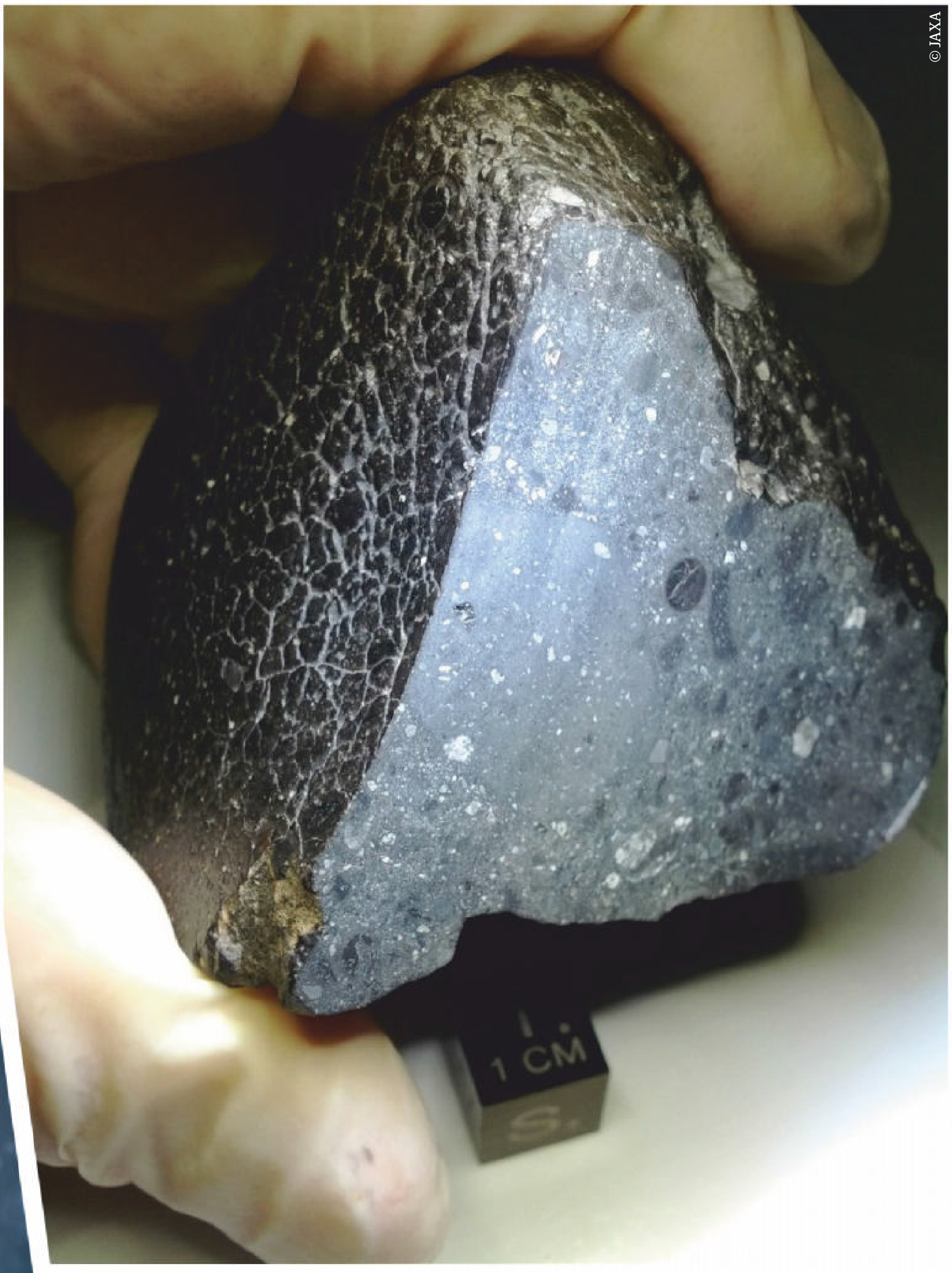
Although the question will continue to linger, there are missions and methods that are bringing exciting results that could help answer the age-old question of where life came from. When this kind of philosophical question can be answered by science, we can truly begin to understand our place within the universe.

Above: JAXA will retrieve the asteroid sample in 2020 from a remote desert in Australia

Above right: Mars had an ocean taking up 20 per cent of its surface

Right: People often find Martian meteorites all over the globe

Below: Without amino acids there is no protein and no DNA



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ASK Space

Our experts answer your questions

COSMOLOGY

Could dark matter have existed before the Big Bang?

Depends on what is meant by the Big Bang. If it refers to a hypothetical 'Big Bang singularity' where time began, then no. If it refers to the 'hot Big Bang', then the answer can be yes.

What cosmologists mean by the term is the state in which the universe was 13.8 billion years ago. At that point the universe was compressed into a tiny volume, hence its matter content – the matter that today comprises galaxies, stars, planets and us – was very dense and hot. This 'hot Big Bang' state left behind an afterglow that cosmologists now call 'cosmic microwave background radiation'. By measuring it we can directly see an image of the Big Bang and deduce what happened during it.

However, it is possible that there were epochs that preceded the hot Big Bang era. For example, a period of rapid expansion dubbed 'cosmic inflation' likely happened before the hot Big Bang. That would explain why the universe is so homogeneous and isotropic at large scales. It may well be that dark matter has its origins in cosmic inflation, and therefore in times that preceded the Big Bang. This idea can be tested in the near future by observing the distribution of galaxies in the universe.

Tommi Tenkanen is a postdoctoral fellow in Physics and Astronomy at Johns Hopkins University in Baltimore, Maryland

> "A period of rapid expansion, 'cosmic inflation', likely happened before the hot Big Bang"

Supernovae have been seen to occur from a range of circumstances

© Tobias Roetsch

ASTROPHYSICS

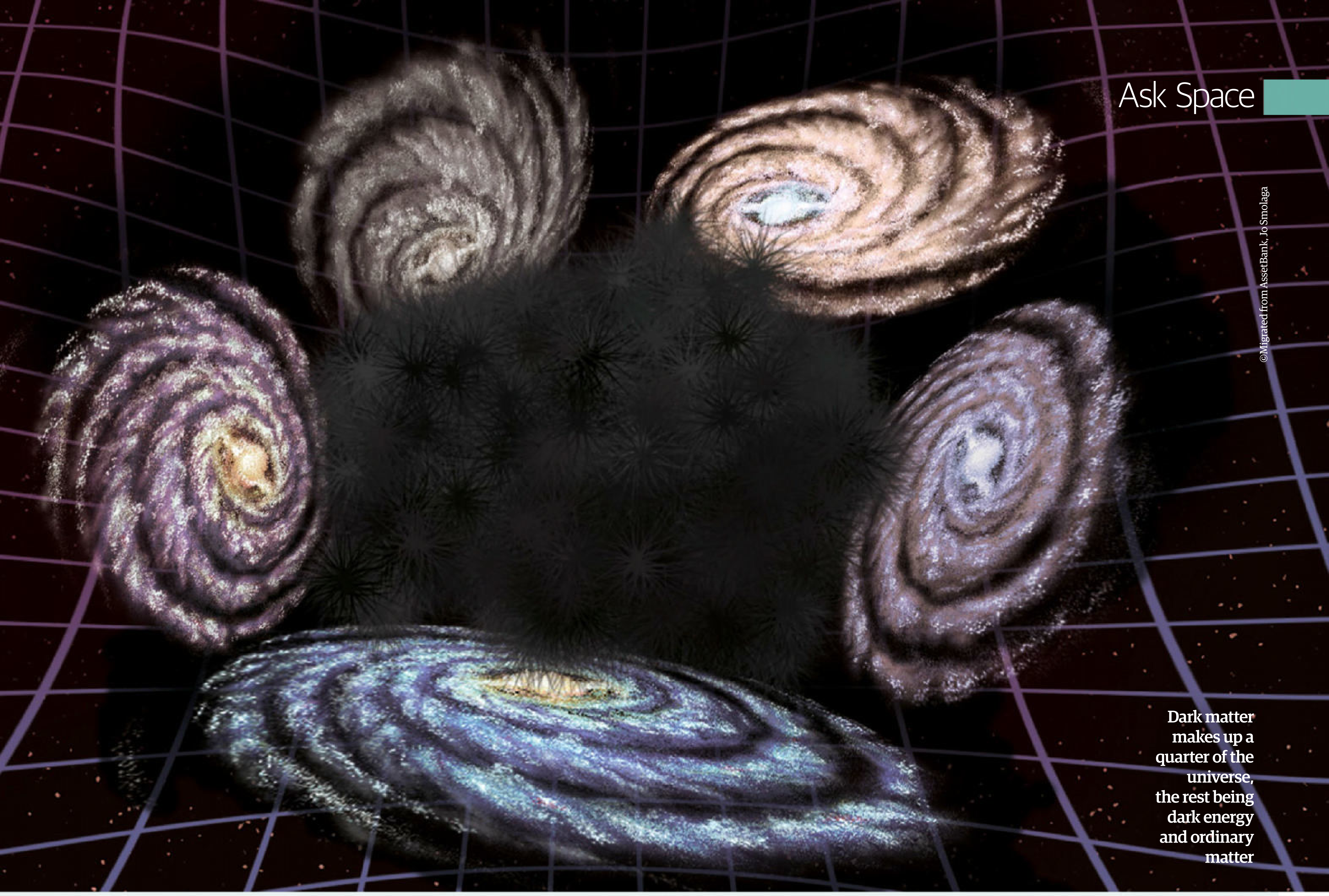
What different types of exploding star are there?

Supernovae have historically been classified into different types based on how their spectra or 'light curve' – a graph depicting how the object's brightness changes over time – looks. The two major types are Type I, a supernova without hydrogen, and Type II, a supernova with hydrogen.

The classifications start getting more convoluted from there. If the supernova has narrow emission lines in its spectra and hydrogen present, then it's called a IIn – 'n' for narrow. If the supernova doesn't have hydrogen but has helium, then it's called a Ib. But if it has neither then it's called a Ic. And then, for example, there are Type IIP supernovae, which have the 'P' designation because they show a plateau in their light curve. In the same way, Type IIL supernovae have a linearly declining light curve. That's in terms of observational properties.

Physically speaking there can be a few types of supernovae. Supernovae can be either the result of the thermonuclear explosion of a white dwarf, or the collapse of the core of a massive star – a core-collapse supernova. And of course there are pair-instability supernovae, which are caused by the production of electron-positron pairs in the cores of stars, which then lead to contraction of the core and an explosion that eventually unbinds the entire star.

Sebastian Gomez is an astrophysicist at the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts



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Dark matter makes up a quarter of the universe, the rest being dark energy and ordinary matter

ASTROPHYSICS

How similar are neutron stars to black holes?

Neutron stars and black holes are similar in some important ways, but are also fundamentally different. They are both celestial bodies which form when sufficiently massive stars exhaust their nuclear fuel and explode as a supernova before gravitationally collapsing in on themselves. Black holes formed by gravitational collapse result from more massive stars, and all known black holes of this type have masses more than five solar masses – one solar mass being the Sun's mass. Currently a hot topic of investigation, neutron stars, which result from the collapse of less massive stars, are thought to have masses in the range between 1.4 solar masses and up to possibly as high as 2.7 solar masses.

Black holes and neutron stars are the densest and most exotic objects in the universe. In the case of a black hole, its progenitor star will continue gravitationally collapsing until all its mass is concentrated at its centre, creating a singularity – a point of space-time with infinite density. We need a theory of quantum gravity to correctly describe what is happening there. This singularity is hidden from the rest of the universe by a boundary surrounding it called the 'event horizon' through which nothing can escape outwards – thus the label 'black'.

In the case of a neutron star, the less massive progenitor star will not collapse all the way to the centre, but instead forms the densest accumulation of actual matter of any object in the universe. The nature of this matter remains a mystery, one which we hope to probe by analysing the gravitational waves and other signals emitted when binary systems of two neutron stars or a black hole and a neutron star collide.

Susan Scott is a professor at the Australian National University's Research School of Physics and Engineering

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These two objects are two of the densest objects found in the universe

ASK Space

Our experts answer your questions

Stardust is essentially comprised of everything in the cosmos, but it is rare to find it in its purest form

© NASA/JPL-Caltech/T. Pyle

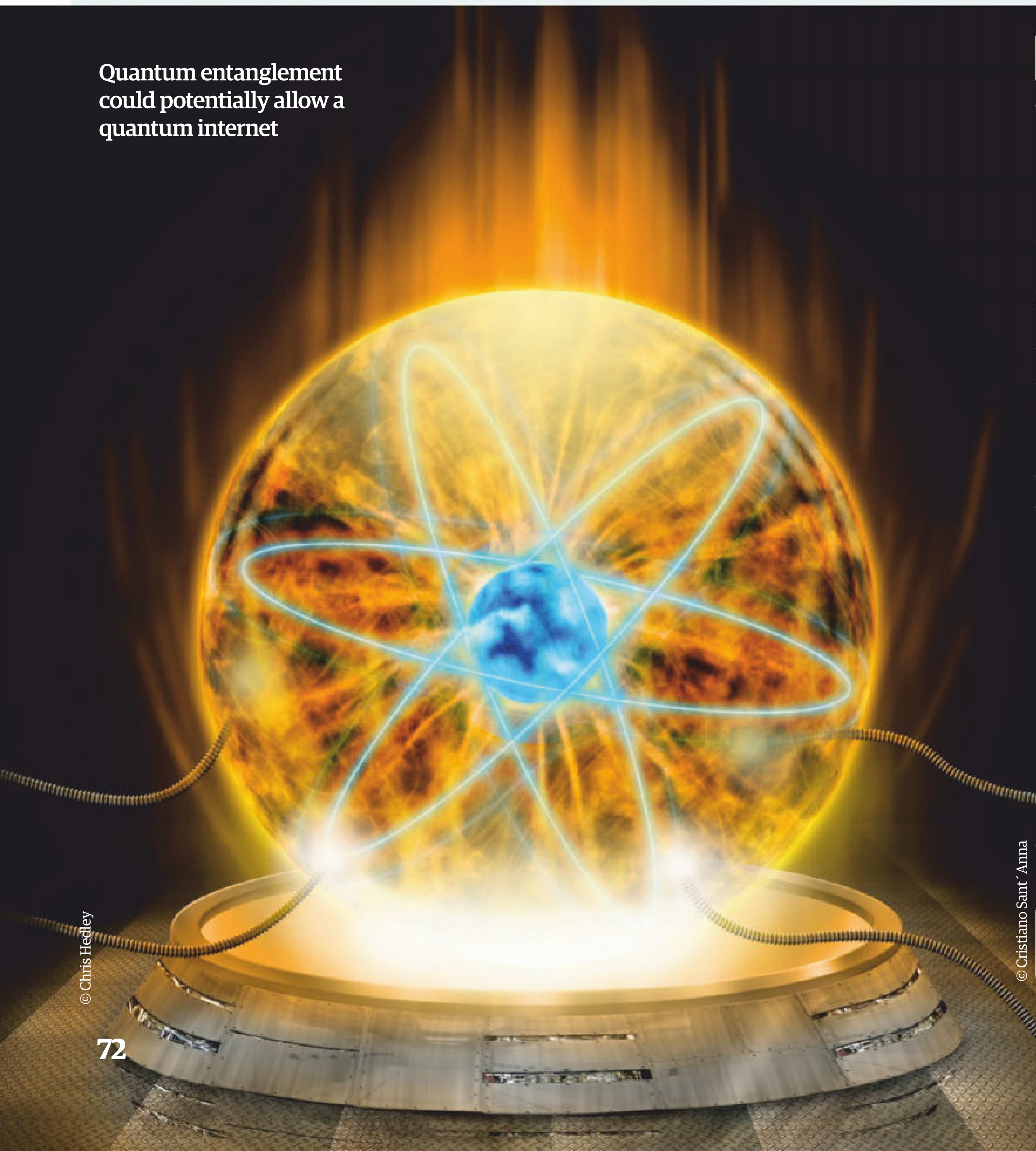
SOLAR SYSTEM

What is 'stardust', and how do we find it on Earth?

Stardust is interstellar grains of different origins. Stars are releasing dust particles at different times during their lives. One of the main sources of interstellar dust are supernovae. Stars heavier than about ten solar masses end their lives in giant explosions. From earlier measurements we know that around 2.5 million years ago a supernova, not too far away from the Solar System, exploded. It left its traces on Earth - one is a very long-lived radionuclide isotope, namely iron-60, that does not exist naturally on Earth. It has been found in dated layers of deep ocean ferromanganese crusts.

To find and identify present stardust on Earth we need unquestionable marks. To collect stardust we have to go to areas undisturbed by natural dust from Earth's soil. Therefore we've been to Antarctica and collected around 500 kilograms (1,100 pounds) of recent snow, hoping that it contains minute amounts of stardust originating from the past supernova. It seems a feasible approach as the Solar System is presently moving through a dusty cloud that could have its origin from this supernova in the past. A clear signal would be the finding of iron-60 that enters the Solar System and rains at present on Earth. After filtering and chemical preparation we analysed milligram-sized samples for iron-60. For this we used one of the world's most sensitive accelerator mass spectrometry set-ups, that in Munich, Germany. Less than ten clearly identified events confirmed the supernova-origin of the Solar System-imbedding cloud.

Gunther Korschinek actively searches for stardust in Antarctica and is a scientist at Technical University Munich, Germany



Quantum entanglement could potentially allow a quantum internet

© Chris Hedley

ASTROPHYSICS

What is 'quantum entanglement', especially in terms of teleportation?

Well, Einstein hated quantum entanglement because it seemed to violate his theory of relativity. If I have two electrons arriving in unison, and then separate them, an umbilical cord - an invisible umbilical cord - emerges connecting the two together. If I jiggle one, the other particle somehow senses the presence of what is happening to its twin. This sensing process goes faster than the speed of light. So Einstein hated this process, and he actually used it to try and disprove quantum mechanics.

Well, Einstein was wrong. We can do this experiment in the laboratory. However, Einstein has the last laugh, because it turns out that usable information cannot be transferred this way. The information transmitted is random. However, some scientists say that if you go below the speed of light, then quantum teleportation may be possible at sub-light speeds.

Quantum teleportation is a little bit different than what you see in Star Trek! We're talking about information travelling from one point to another point. We've done this with atoms and photons. We can teleport particles over hundreds of feet. In fact, we can do this in principle to the Moon!

© Cristiano Sant' Anna

Michio Kaku is a popular science communicator and professor of theoretical physics at the City College of New York

Did you know?

The Lunar Orbital Platform, formerly proposed as the Deep Space Gateway, is the next stage in human exploration. Development includes all the ISS partners.

The Lunar Orbital Platform will be a collaborative effort between international organisations

© Boeing

SPACE EXPLORATION

What are the main challenges you have to overcome creating the Lunar Orbital Platform?

The work that's going on at the moment is the international partners working together to understand what the Deep Space Gateway would look like and discuss the different roles the partners would play and the different elements that they would prepare.

So say one agency may contribute a habitat, another agency [would contribute] the robotic parts and another agency something else. [At the moment] it is understanding - the same as with the International Space Station - it's really a partnership where everybody discusses what do we want to get out of this, what do we want to bring, what are we going to contribute.

I think now is the time where we are working out, technically, what the thing looks like, what it needs to do, what the engineering side is. We need to talk to our partners internationally to define that and to define our roles.

We need to work with the stakeholders of the different agencies to identify how the thing will be supported [financially]. We also need to work with the science community, and other beneficiaries of the project, to make sure they're engaged and aware of the opportunity.

When the opportunity has arisen we need to make sure that they're able to respond to the opportunity with the intention that the gateway would be put together in the lunar vicinity in the early parts of the next decade, not many years from now.

James Carpenter is the human and robotic exploration strategy officer at the European Space Agency (ESA)

SPACE EXPLORATION

Are the current space treaties, drafted in the 1960s and 1970s, now considered outdated?

It is true that they are a testament to the era in which they were adopted. However, to my mind, the crucial problem we're facing does not concern the time that has passed since then. Rather, it lies in the near absence of acknowledgment in law that space affairs then and later would be used for military purposes.

We are more than capable of interpreting laws that have existed for a while, which you clearly see with, for example, the European Convention on Human Rights. It was drafted in 1950, but it is seen today as a 'living instrument', and the Strasbourg court interprets its provisions on a daily basis. The same goes for the Geneva Conventions of 1949, which are meant to regulate the conduct of hostilities and protect the victims of armed conflict. Almost seven decades have passed since the rules were adopted, but they are still very much implemented by the militaries around the world every day. But we don't have rules that would expressly regulate military conduct in outer space.

Kubo Mačák is a senior lecturer in law at the University of Exeter

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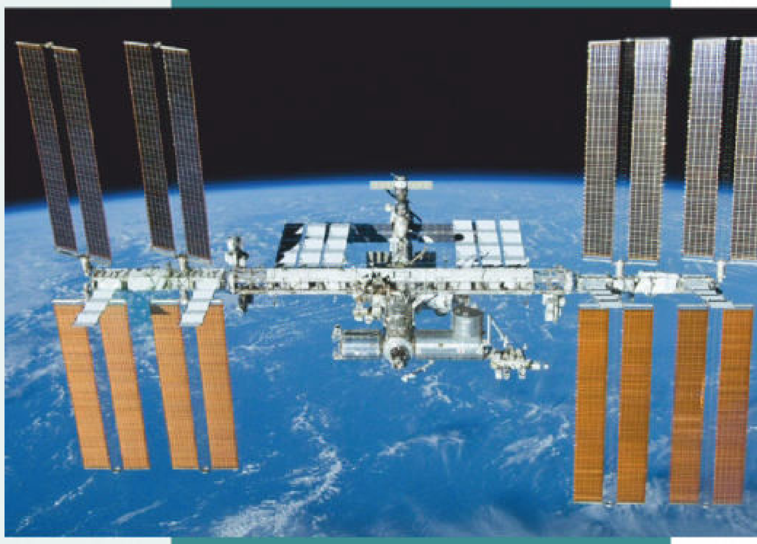


GREATEST STARGAZING SITES TO VISIT IN 2020

All About Space leaves the bright city lights to observe at the world's darkest locations

Ask any astronomer what their greatest hindrance is during a typical observing session and you're likely to be answered quite quickly with 'light pollution'. That's because this misdirected and often excessive artificial light seeps into the night from lit-up towns and cities, washing out the faint dark-sky treasures that stargazers take great pleasure in imaging and gazing upon. And, with more areas becoming built up, the problem seems to be getting worse, obscuring our beautiful starry skies with an orange haze.

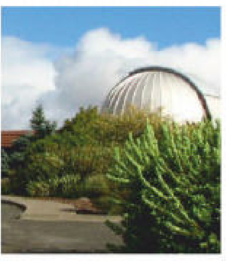
That's why the International Dark Sky Association (IDA) is the astronomer's best friend. Working with parks, reserves and communities to keep areas relatively free from light, the IDA also focuses on heavily lit regions by finding ways to keep lighting to a minimum or suggesting night-sky friendly streetlights. The stargazer's enemy is slowly being beaten in certain areas, allowing astronomers to be able to retreat into certified International Dark Sky regions undisturbed. **All About Space** visits 20 of them.

© NPS / Jacob W. Frank

Natural Bridges National Monument

LOCATION: Lake Powell, Utah
AREA: 30.9km²

Named the world's first International Dark Sky Park back in March 2007, Natural Bridges boasts some of the darkest skies in the entirety of the US. Earning Gold Tier status, its designation not only recognises the pitch blackness, but also the efforts gone to ensure that the park's natural darkness is conserved. Allowing astronomers to camp in the park's grounds, observers can take advantage of the stunning skies.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Goldendale Observatory State Park

Location: Washington
Area: 0.02km²

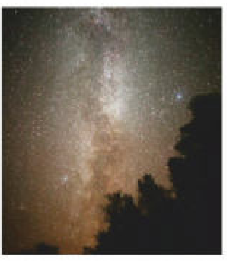
Designated as a Dark Sky Park in 2010, Goldendale doubles up as an educational facility, positioned on a hill with an observatory and several telescopes. Its main instrument is a 24.5-inch reflecting telescope that takes up to 40,000 visitors per year.

© Terence Dickinson

Cherry Springs State Park

Location: Pennsylvania
Area: 0.33km²

An astronomer's paradise, its elevation atop the dissected Allegheny Plateau enables Cherry Springs to boast some of the best night skies along the United States' east coast. It's so dark that the Milky Way casts a shadow, and some 10,000 stars are visible without aid.


© James Hilder

Galloway Forest Park

Location: Dumfries and Galloway, Scotland
Area: 774km²

In November 2009 and during the International Year of Astronomy, woodland park Galloway Forest Park became the first-ever area in the whole of the United Kingdom to earn the status of being classed as a region with outstanding night skies.

© Wiki, ESO/A. Fitzsimmons

Zselic National Landscape Protection Area

Location: Zselic, Hungary
Area: 83km²

Hailed as some of the best dark skies in Hungary, the Zselic National Landscape Protection Area allows not only the Milky Way to be visible to the naked eye but also zodiacal light and other faint phenomena. Zselic was awarded dark sky status in 2009.

© Michael Sinclair

Brecon Beacons National Park

Location: Brecon, Wales
Area: 1,344km²

The Brecon Beacons is known for its mountainous peaks in South Wales. While the skies above the park do see a touch of light pollution, it won Silver Tier status as the heavens remain remarkably dark, revealing the Milky Way among other night-sky objects.

© Tyler Nordgren

Big Bend National Park

Location: Texas
Area: 3,242km²

As soon as the Sun sets at Big Bend National Park, it's not just the many species of nocturnal life that come out, it's also the night-sky delights that permeate the black-as-coal skies. A remote expanse of desert, mountains, canyons, open floodplains and rapids, the park possesses some of the most enviable dark skies in the United States, certifying it as a location virtually free from light pollution.

Northern naked-eye delights

Binocular or telescope objects become naked-eye targets under exceptionally dark skies

The Andromeda Galaxy (M31)

Object	Spiral galaxy
Right Ascension	00h 42m 44.3s
Declination	−41° 16' 09"
Constellation	Andromeda
Apparent Magnitude	+3.44

The Orion Nebula (M42)

Object	Reflection and emission nebula
Right Ascension	5h 35m 17.3s
Declination	−05° 23' 28"
Constellation	Orion
Apparent Magnitude	+4.0

Triangulum Galaxy (M33)

Object	Spiral galaxy
Right Ascension	01h 33m 50s
Declination	+30° 39' 36.7"
Constellation	Triangulum
Apparent Magnitude	+5.72

North America Nebula (NGC 7000)

Object	Emission nebula
Right Ascension	20h 59m 17.1s
Declination	+44° 31' 44"
Constellation	Cygnus
Apparent Magnitude	+4.0

Stunning southern sights

The dark skies of the Southern Hemisphere reveal these naked-eye gems

Eta Carinae Nebula (NGC 3372)

Object	Emission Nebula
Right Ascension	10h 45m 8.5s
Declination	-59° 52' 04"
Constellation	Carina
Apparent Magnitude	+1.0

Large and Small Magellanic Clouds

Object	Irregular dwarf galaxies
Right Ascension (LMC/SMC)	05h 23m 34.5s/00h 52m 44.8s
Declination (LMC/SMC)	69° 45' 22"/-72° 49' 43"
Constellation (LMC/SMC)	Dorado & Mensa/Tucana
Apparent Magnitude	+0.9/+2.7

Omega Centauri (NGC 5139)

Object	Globular cluster
Right Ascension	13h 26m 47.3s
Declination	-47° 28' 46.1"
Constellation	Centaurus
Apparent Magnitude	+3.9

Alpha Centauri

Object	Binary star system
Right Ascension	14h 36m 36.5s
Declination	-60° 50' 02.4"
Constellation	Centaurus
Apparent Magnitude	+0.01

© Madhav Rajesh

Clayton Lake State Park

Location: New Mexico

Area: 1.9km^2

A recreational reservoir that features a fossil trackway of dinosaur footprints, this state park hits the Gold Tier when it comes to its dark skies and the efforts that have gone into preserving its darkness. Clayton Lake State Park also features the Star Point Observatory.

© International Dark Sky Association

Hortobágy National Park

Location: Hortobágy, Hungary

Area: 74.8km^2

The largest continuous natural grassland in Europe is bound to be open to incredibly dark night skies. And that's where Hortobágy National Park comes in, opening up the opportunity for amateur astronomers to grab a stunning view of almost any night-sky object of their choice.

© International Dark Sky Association

Geauga Observatory Park

Location: Ohio

Area: 4.18km^2

Earning its designation in 2011, Observatory Park is currently in the process of restoring its historic Nassau Astronomical Observing Station. The park offers several seasonal programmes under its skies, as well as within the Oberle Observatory.

© Wilson Ye wilsonye123

Death Valley National Park

Location: California

Area: 13,650km^2

A place to gaze in awe at the expanse of the Milky Way, track a meteor shower or simply to reflect on your place in the universe, Death Valley boasts natural darkness that represents the efforts of the park and amateur astronomers who have sought the area's starry skies for decades.

© Jan Erik Paulsen

Exmoor National Park

Location: Somerset and Devon, England

Area: 692km^2

Designated in 2011, Exmoor National Park has the combined beauty of enjoying the blackest skies along the southwest coast of England while offering relatively easy access from its urban hubs. Along with its designation, the park offers astronomy programmes, making it a popular place for astronomers to take full advantage of the beautiful heavens above.

© International Dark Sky Association

Mont-Mégantic National Park

Location: Quebec, Canada

Area: 54.86km^2

This stunning Canadian park, which was created in 1994, boasts the most important astronomical observatory in eastern Canada – Mont-Mégantic Observatory at the peak of Mont-Mégantic, as well as ASTROLab, an astronomy activity centre devoted to making science accessible.

© International Dark Sky Association

The Headlands

Location: Michigan

Area: 2.2km^2

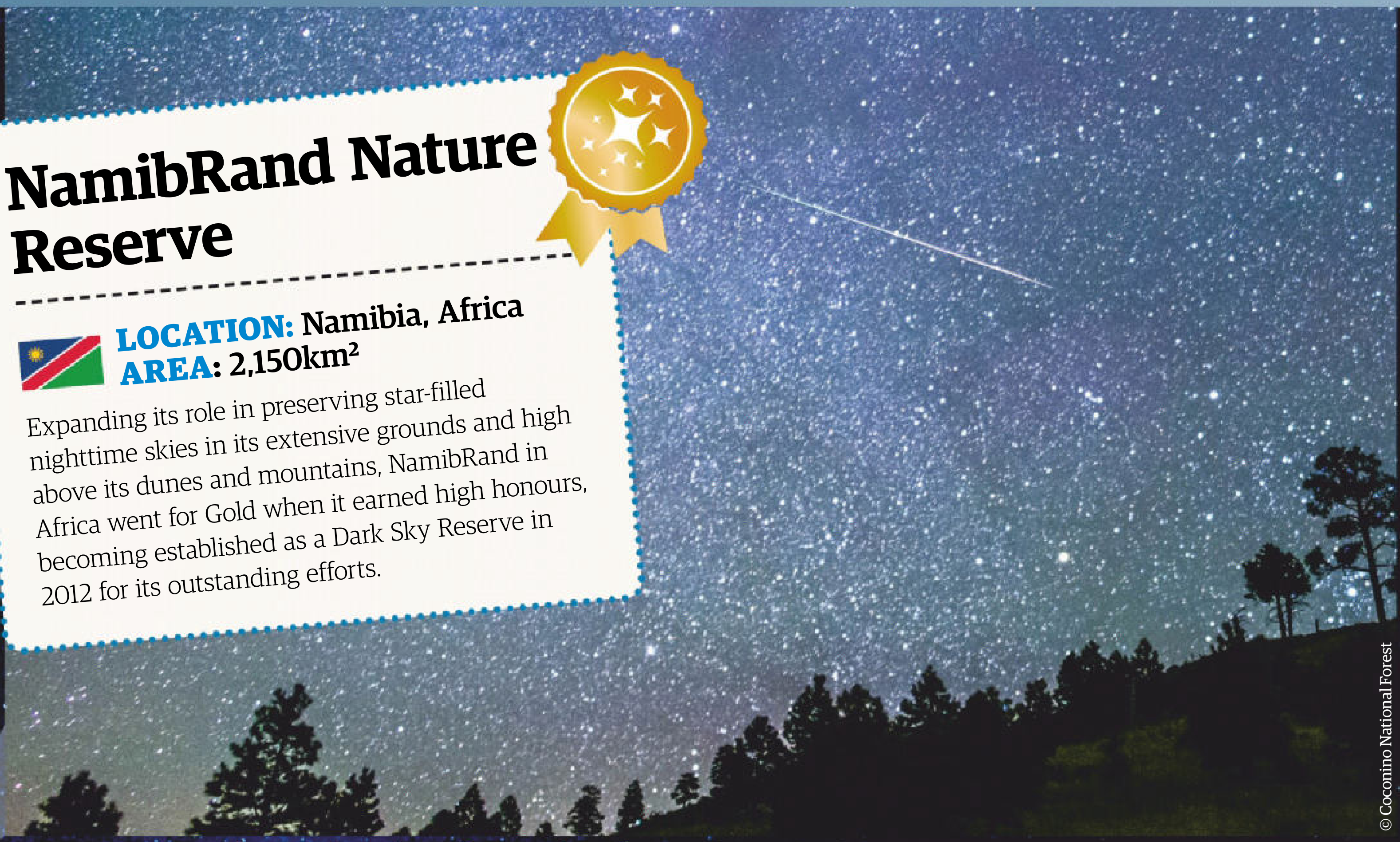
Represented by its old-growth forests that sit on undeveloped Lake Michigan shoreline, The Headlands boasts the darkest of skies, undiluted by light pollution, that will continue to be preserved into the foreseeable future. Astronomers are able to take part in the monthly free Dark Sky programmes.

© Jonatan Pie r3dmax

Northumberland National Park and Kielder Water and Forest Park

LOCATION: Northumberland, England **AREA:** 1,050km^2

Once at the frontier of Roman Britain, this Dark Sky Park is one of the darkest locations in England. With the opportunity to provide local astronomy events and activities involving Britain's largest and most active public observatory - Kielder Observatory - this part of the UK attracts many visitors.


© Coconino National Forest

NamibRand Nature Reserve

LOCATION: Namibia, Africa
AREA: 2,150km²

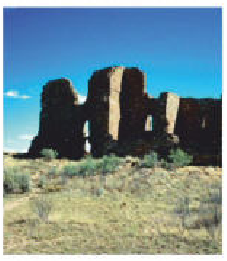
Expanding its role in preserving star-filled nighttime skies in its extensive grounds and high above its dunes and mountains, NamibRand in Africa went for Gold when it earned high honours, becoming established as a Dark Sky Reserve in 2012 for its outstanding efforts.

© International Dark Sky Association

Aoraki Mackenzie International Dark Sky Reserve

Location: South Island, New Zealand **Area:** 4,300km²

Possessing the title of the largest International Dark Sky Reserve in the world, New Zealand's Aoraki Mackenzie – comprised of Aoraki/Mount Cook National Park and the Mackenzie Basin – is almost totally free from the glare of light pollution, with outdoor lighting controls minimising its effects for stargazers in the reserve and nearby Mount John Observatory.


© HJPD

Chaco Culture National Historic Park

Location: New Mexico
Area: 137.5km²

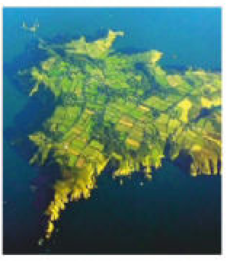
Not only taking care of its archaeological riches since the park was established in 1907, Chaco also protects its starry skies, ensuring that light pollution doesn't spoil the pristine heavens with its strict lighting guidelines.

© Paul Compere

Pic du Midi International Dark Sky Reserve

Location: Pyrénées, France
Area: 3,112km²

Celebrating their first International Dark Sky Reserve at the end of 2013, France's Pic du Midi has made every effort to protect their exceptionally dark night skies over the Pyrénées Mountains.


© Phillip Capper

Sark

Location: Channel Islands
Area: 5.45km²

The first Dark Sky Island, Sark forms what we know today as an International Dark Sky Community alongside Flagstaff in Arizona, Borrego Springs in California, Homer Glen in Illinois and Coll in the Inner Hebrides of Scotland. The island places a ban on cars and is mostly devoid of any public lighting.

Night-sky safety

Consider your safety before setting out to a dark-sky park. How flat is the terrain that you'll be walking across? Are there steps? Be sure to bring a mobile phone, food, drink and warm clothing for the cold night ahead. If you're camping, make sure that you've planned where you'll be pitching your tent the day before. Ensure you bring a red-filter torch with you – you'll be able to see night sky maps and where you're going while preserving your night vision.

✦ ✦ ✦

Bortle scale

Consisting of a nine-level numeric scale, the Bortle scale – named for its creator, astronomer John Bortle – measures the night sky's brightness in a particular location, quantifying the observability of an astronomical object and the interference caused by light pollution. Bortle scale 1 relates to an excellent dark sky site, while an inner city sky is represented by Bortle scale 9.

Gold, silver or bronze?

GOLD

Artificial light and skyglow: Observer isn't distracted by the glare of light sources. Light domes are dim and restricted to the sky closest to the horizon.

Faintest magnitude visible: Equal or greater than 6.8 with clear skies and good seeing conditions.

Bortle sky class: 1-3

Observable objects: Full visible sky objects such as the Milky Way, zodiacal light, faint meteors.

Sky Quality Meter reading: 21.75 or above.

SILVER

Artificial light and skyglow: Sky not dominated by point light sources and glare from lights. Light domes around the horizon do not stretch to zenith.

Faintest magnitude visible: 6.0 to 6.7 under clear skies and good conditions.

Bortle sky class: 3-5

Observable objects: Brighter visible sky objects regularly viewed, with fainter ones sometimes visible. Milky Way visible in summer and winter.

Sky Quality Meter reading: 21.00 or above.

BRONZE

Artificial light and skyglow: Greater artificial light and skyglow than Silver, but some natural sky is still visible.

Faintest magnitude visible: 5.0 to 5.9 under clear skies and good conditions.

Bortle sky class: 5-6

Observable objects: Many sky phenomena are difficult to see. However, the Milky Way and the Andromeda Galaxy are visible when pointed out.

Sky Quality Meter reading: 20.00 or above.

STARGAZER

ESSENTIAL GUIDES AND ADVICE FOR AMATEUR ASTRONOMERS

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What's in the sky?

10 OCT
The Southern Taurids reach their peak of five meteors per hour

©Wiki

11 OCT
The Delta Aurigids reach their peak of two meteors per hour

15 OCT
Mercury reaches its highest point in the evening sky

17 OCT
Dwarf planet Eris reaches opposition in Cetus

18 OCT
The Eta Geminids reach their peak of three meteors per hour

© Wiki

24 OCT
The Leonis Minorids reach their peak of two meteors per hour

26 OCT
Asteroid 9 Metis is well placed for observation, glowing at magnitude 8.6 in Cetus

31 OCT
Conjunction between the Moon and Jupiter in Ophiuchus

31 OCT
The Moon and Jupiter make a close approach, passing within 1°17′ of each other in Ophiuchus

2 NOV
Conjunction between the Moon and Saturn

Red light friendly

In order to preserve your night vision, you should read our observing guide under red light

Jargon buster

Conjunction

A conjunction is an alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

Right Ascension (RA)

Right Ascension is to the sky what longitude is to the surface of the Earth, corresponding to east and west directions. It is measured in hours, minutes and seconds since, as the Earth rotates on its axis, we see different parts of the sky throughout the night.

Declination (Dec)

This tells you how high an object will rise in the sky. Like Earth's latitude, Dec measures north and south. It's measured in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and there are 60 arcminutes in a degree.

Magnitude

An object's magnitude tells you how bright it appears from Earth. In astronomy, magnitudes are represented on a numbered scale. The lower the number, the brighter the object. So, a magnitude of -1 is brighter than an object with a magnitude of +2.

Opposition

When a celestial body is in line with the Earth and Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter.

Greatest elongation

When the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as evening stars at greatest eastern elongations and as morning stars during western elongations.

13 OCT

Asteroid 29 Amphitrite is well placed for observation, glowing at magnitude 8.7 in Pisces

©Wiki

15 OCT

The Triangulum Galaxy (M33) is well placed for observation, glowing at magnitude 5.7

20 OCT

Mercury is at its greatest elongation, shining brightly at magnitude -0.1

21 OCT

The Orionids reach their peak of 15 meteors per hour

26 OCT

Open cluster NGC 869 is well placed for observation, glowing at magnitude 3.7 in Perseus

27 OCT

Open star cluster NGC 884 is well placed for observation, glowing at magnitude 3.8 in Perseus

28 OCT

Uranus reaches opposition, glowing at magnitude 5.7 in Aries

2 NOV

The Moon and Saturn make a close approach, passing within 0°35' of each other in Sagittarius

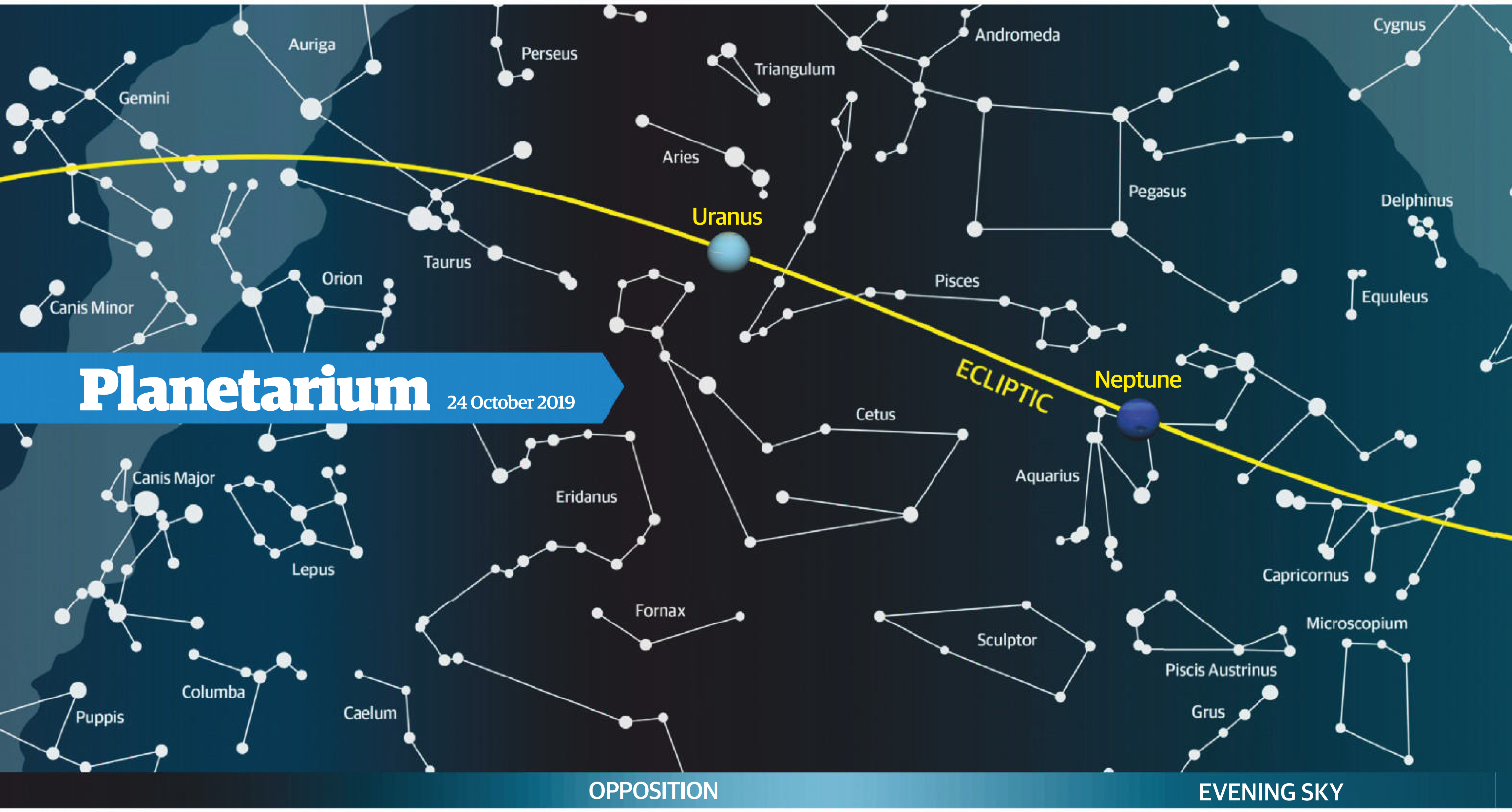
2 NOV

The Moon and Pluto make a close approach, passing within 0°23' of each other in Sagittarius

- Naked eye
- Binoculars
- Small telescope
- Medium telescope
- Large telescope

Planetarium

24 October 2019



Moon calendar

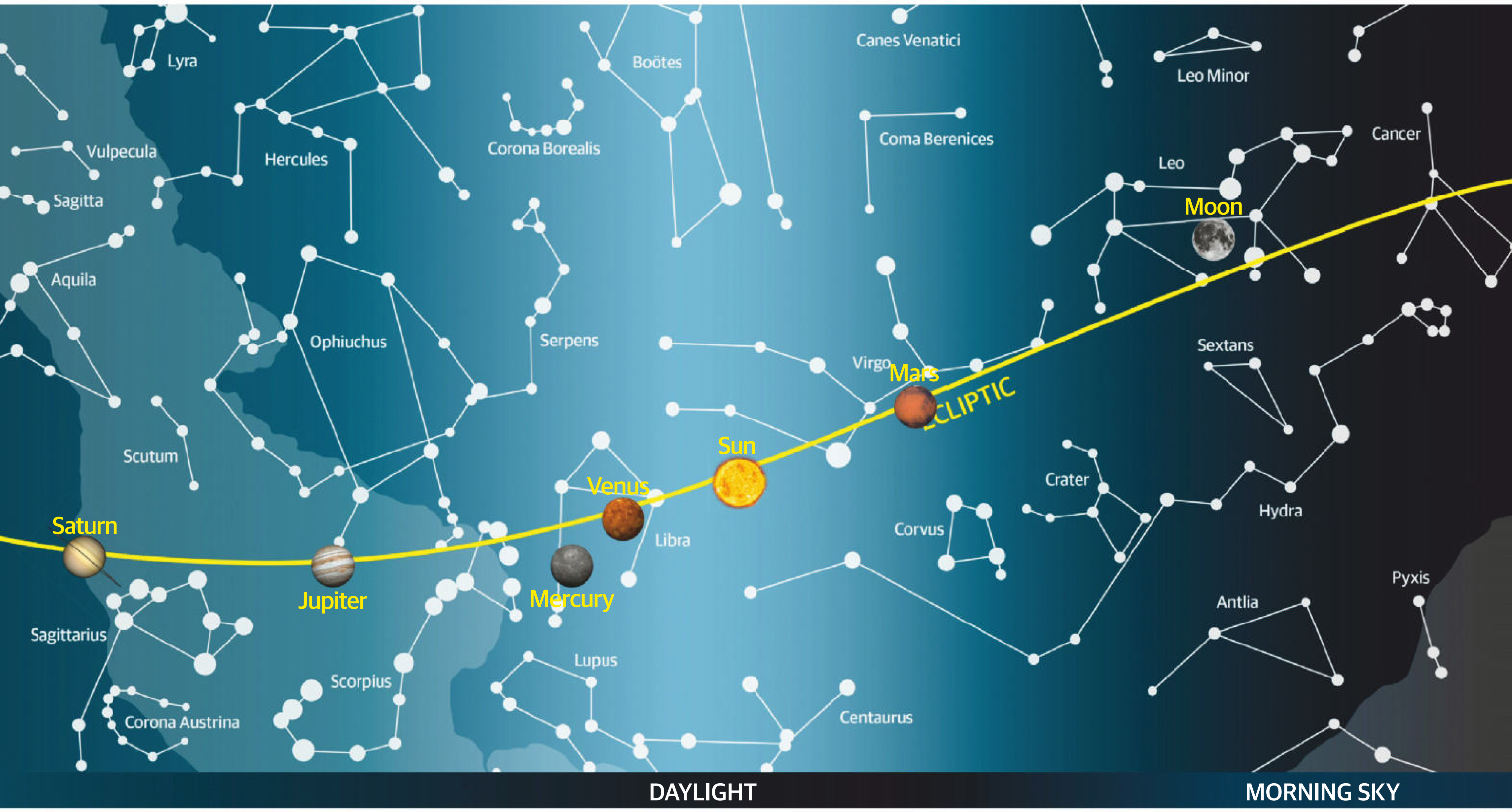
* The Moon does not pass the meridian on 12 October

10 OCT		92.0%	◡03:09	◠17:42
11 OCT		96.4%	◡04:16	◠18:01
12 OCT		--.-*%	◡05:22	◠18:18
13 OCT	FM	99.0	◡06:28	◠18:35
14 OCT		99.8%	◡07:35	◠18:53
15 OCT		98.6%	◡08:43	◠19:13
16 OCT		95.4%	◡09:53	◠19:36
17 OCT		90.2%	◡11:03	◠20:04
18 OCT		83.2%	◡12:12	◠20:39
19 OCT		74.5%	◡13:18	◡21:24
20 OCT		64.4%	◡14:16	◠22:21
21 OCT	LQ	53.3%	◠15:06	◡23:29
22 OCT		41.7%	◠15:46	◡--:--
23 OCT		30.4%	◡00:45	◠16:19
24 OCT		19.9%	◡02:07	◠16:46
25 OCT		11.0%	◡03:31	◠17:10
26 OCT		4.5%	◡04:56	◠17:32
27 OCT		0.9%	◡05:21	◠16:55
28 OCT	NW	0.3%	◡06:46	◠17:19
29 OCT		2.8%	◡08:09	◠17:46
30 OCT		7.9%	◡09:30	◠18:19
31 OCT		15.1%	◠10:44	◡18:59
1 NOV		23.8%	◠--.--	◡08:53
2 NOV		33.4%	◠--.--	◡10:07
3 NOV		43.3%	◠--.--	◡11:22
4 NOV	FQ	53.3%	◡12:37	◠22:30
5 NOV		63.0%	◡13:50	◠23:11
6 NOV		72.1%	◡14:59	◠--.--
7 NOV		80.3%	◡01:03	◠15:07

% Illumination
◠ Moonrise time
◡ Moonset time

FM Full Moon
NM New Moon
FQ First quarter
LQ Last quarter

All figures are given for 00h at midnight (local times for London, UK)



Illumination percentage

	17 OCT	24 OCT	31 OCT	5 NOV
MERCURY	70%	50%	30%	10%
VENUS	100%	90%	90%	90%
MARS	100%	100%	100%	100%
JUPITER	100%	100%	100%	100%
SATURN	100%	100%	100%	100%

Planet positions

All rise and set times are given in BST/GMT

	Date	RA	Dec	Constellation	Mag	Rise	Set
MERCURY	10 Oct	14h 23m 01s	-16° 22' 17"	Libra	-0.1	09:40	18:55
	17 Oct	14h 56m 15s	-19° 35' 20"	Libra	-0.1	10:05	18:41
	24 Oct	15h 23m 31s	-21° 44' 24"	Libra	-0.1	10:18	14:23
	31 Oct	15h 37m 27s	-22° 17' 56"	Libra	0.4	09:08	13:09
	5 Nov	15h 32m 27s	-21° 11' 03"	Libra	1.6	08:36	12:44
VENUS	10 Oct	13h 57m 38s	-11° 21' 55"	Virgo	-3.9	08:47	18:58
	17 Oct	14h 30m 57s	-14° 30' 11"	Libra	-3.9	09:10	18:46
	24 Oct	15h 05m 11s	-17° 21' 04"	Libra	-3.9	09:33	18:36
	31 Oct	15h 40m 24s	-19° 50' 06"	Libra	-3.9	08:55	17:29
	5 Nov	16h 06m 10s	-21° 20' 42"	Scorpius	-3.9	09:11	17:25
MARS	10 Oct	12h 14m 17s	-00° 31' 17"	Virgo	1.8	06:08	18:10
	17 Oct	12h 30m 51s	-02° 20' 28"	Virgo	1.8	06:06	17:50
	24 Oct	12h 47m 30s	-04° 09' 06"	Virgo	1.8	06:04	17:30
	31 Oct	13h 04m 19s	-05° 56' 37"	Virgo	1.8	05:03	16:10
	5 Nov	13h 16m 25s	-07° 12' 23"	Virgo	1.8	05:02	15:56
JUPITER	10 Oct	17h 13m 16s	-22° 45' 38"	Ophiuchus	-2.0	13:10	21:05
	17 Oct	17h 18m 11s	-22° 51' 47"	Ophiuchus	-2.0	12:48	20:41
	24 Oct	17h 23m 28s	-22° 57' 38"	Ophiuchus	-2.0	12:26	20:19
	31 Oct	17h 29m 06s	-23° 03' 02"	Ophiuchus	-1.9	11:05	18:56
	5 Nov	17h 33m 18s	-23° 06' 32"	Ophiuchus	-1.9	10:50	18:40
SATURN	10 Oct	19h 00m 50s	-22° 32' 01"	Sagittarius	0.5	14:55	22:54
	17 Oct	19h 02m 04s	-22° 30' 52"	Sagittarius	0.5	14:29	22:27
	24 Oct	19h 03m 37s	-22° 29' 11"	Sagittarius	0.5	14:03	22:02
	31 Oct	19h 05m 28s	-22° 26' 58"	Sagittarius	0.6	12:37	20:36
	5 Nov	19h 06m 58s	-22° 25' 02"	Sagittarius	0.6	12:19	20:18

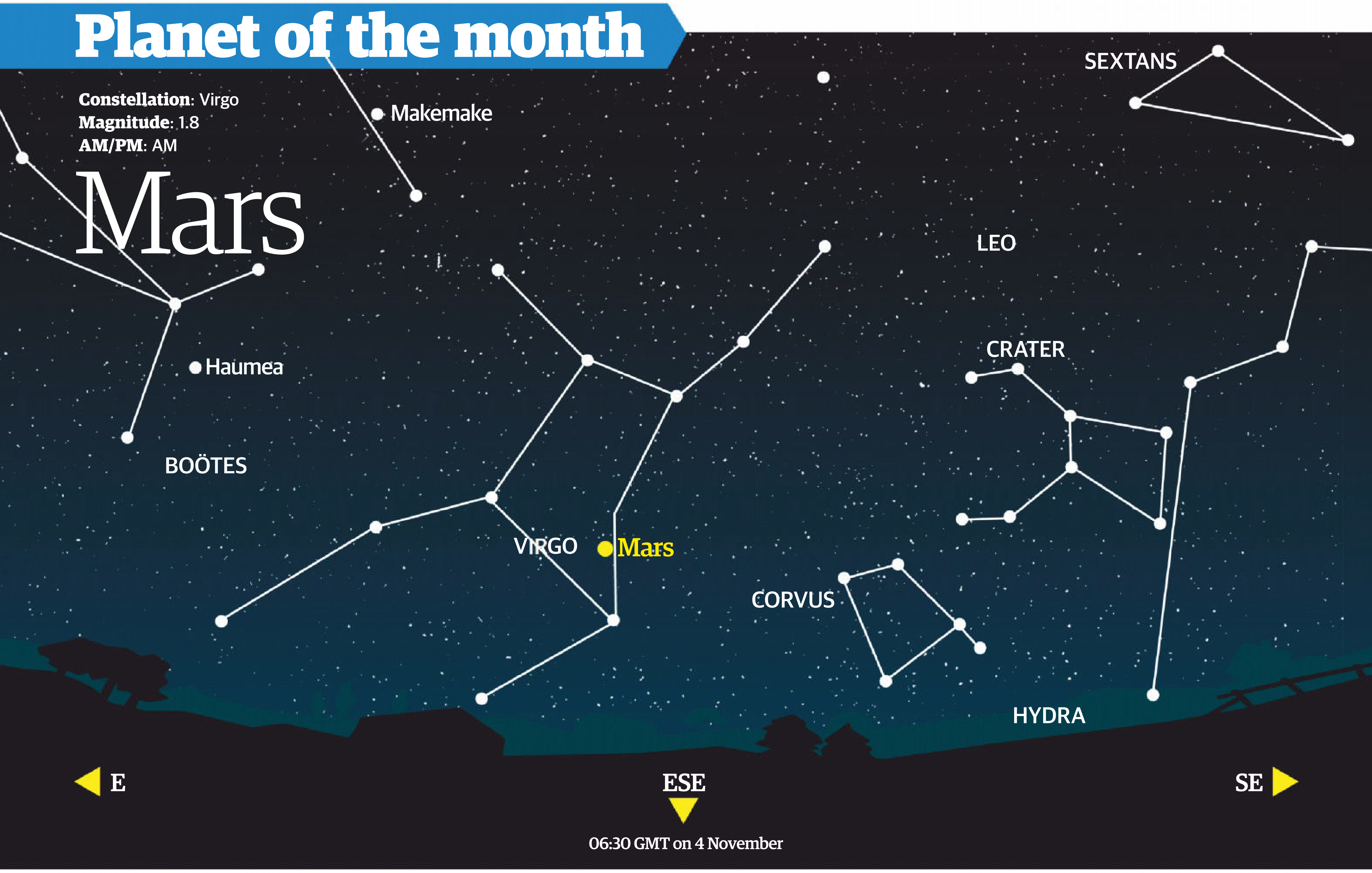
This month's planets

The God of War is a prime target this autumn, and well into the winter, finally breaking free from the Sun

Planet of the month

Constellation: Virgo
Magnitude: 1.8
AM/PM: AM

Mars



06:30 GMT on 4 November

After being out of the celestial spotlight for a while, Mars is finally becoming a little easier to see - and more rewarding to look at, too. This month the Red Planet will be a morning star, visible low in the east before sunrise, and its visibility will improve a little each morning.

Shining at magnitude 1.8 means Mars is nowhere near as bright as Saturn or Jupiter, which are on view in the evening sky this month, but that magnitude of 1.8 means you'll be able to see Mars easily with your naked eye, looking like an orange-white 'star' around the same visual brightness as the stars of the Big Dipper, or Polaris, the 'Pole Star'.

And if you're not quite sure which of the stars in that part of the sky is actually Mars, then its orange hue will give it away, especially through a pair of binoculars. Another clue: by the start of November Mars will be very close to Spica, the brightest star in Virgo. Look for a lovely 'double star' low in the ESE around 06:00 and you'll see them there shining close together. The brighter, bluer one is Spica, and the fainter, redder one is Mars.

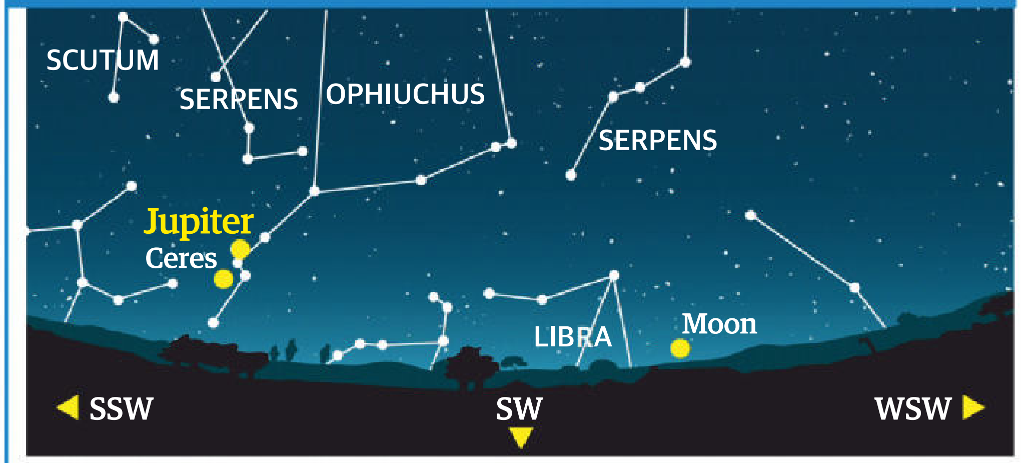
Mars is our Planet of the Month this month not because it is particularly bright or obvious, but because it will be in the headlines. As this issue hits the shelves the construction of the European Space Agency and Roscosmos' ExoMars rover, 'Rosalind Franklin', should be almost complete, and preparations for its launch in July 2020 should be well advanced. The rover is scheduled to touch down on Mars in 2021, in a previously unexplored region called Oxia Planum. It will then drive around the site taking measurements, conducting science and, of course, taking plenty of photographs which will be beamed back to Earth and put on websites soon after for everyone to enjoy.

For these reasons the ExoMars mission promises to be very exciting, and it might even answer one of the greatest questions in astronomy and science: are we alone? Many of its instruments are designed to look for traces of past life on Mars. A drill will bring up samples of rock from up to two metres (6.5 feet) below the surface, where some scientists think there is the best chance of finding those traces - or perhaps even of finding signs of life on Mars today.

So get up early this month to look for Mars in the pre-dawn sky. It might not look very impressive now, but things are about to get very exciting out there on the Red Planet.

This month's planets

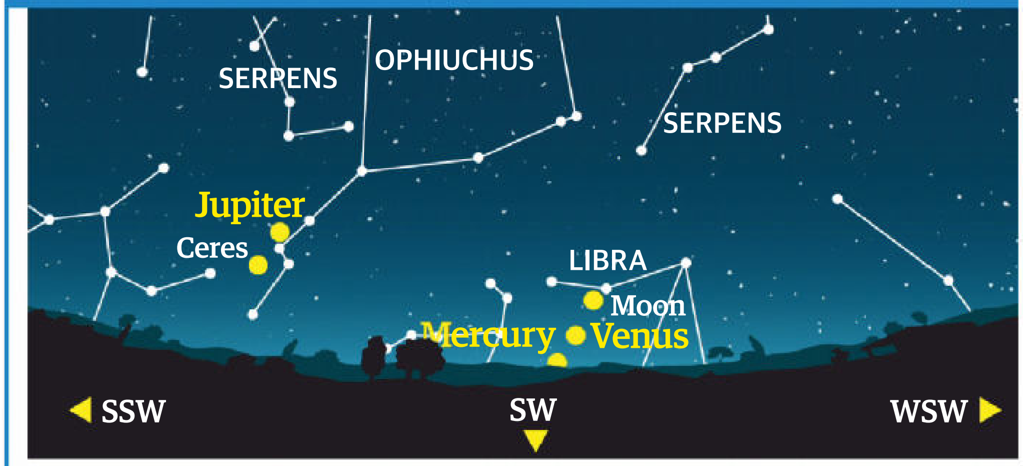
Mercury 17:00 GMT on 28 October



Constellation: Libra
Magnitude: -0.0
AM/PM: PM

Unfortunately this won't be a good month for any Mercury-watchers. The closest planet to the Sun – which whips around it in just 88 days, giving it the shortest year in the Solar System – is not only very low in the southwestern sky after sunset, but is so close to the Sun itself that it will be virtually impossible to see.

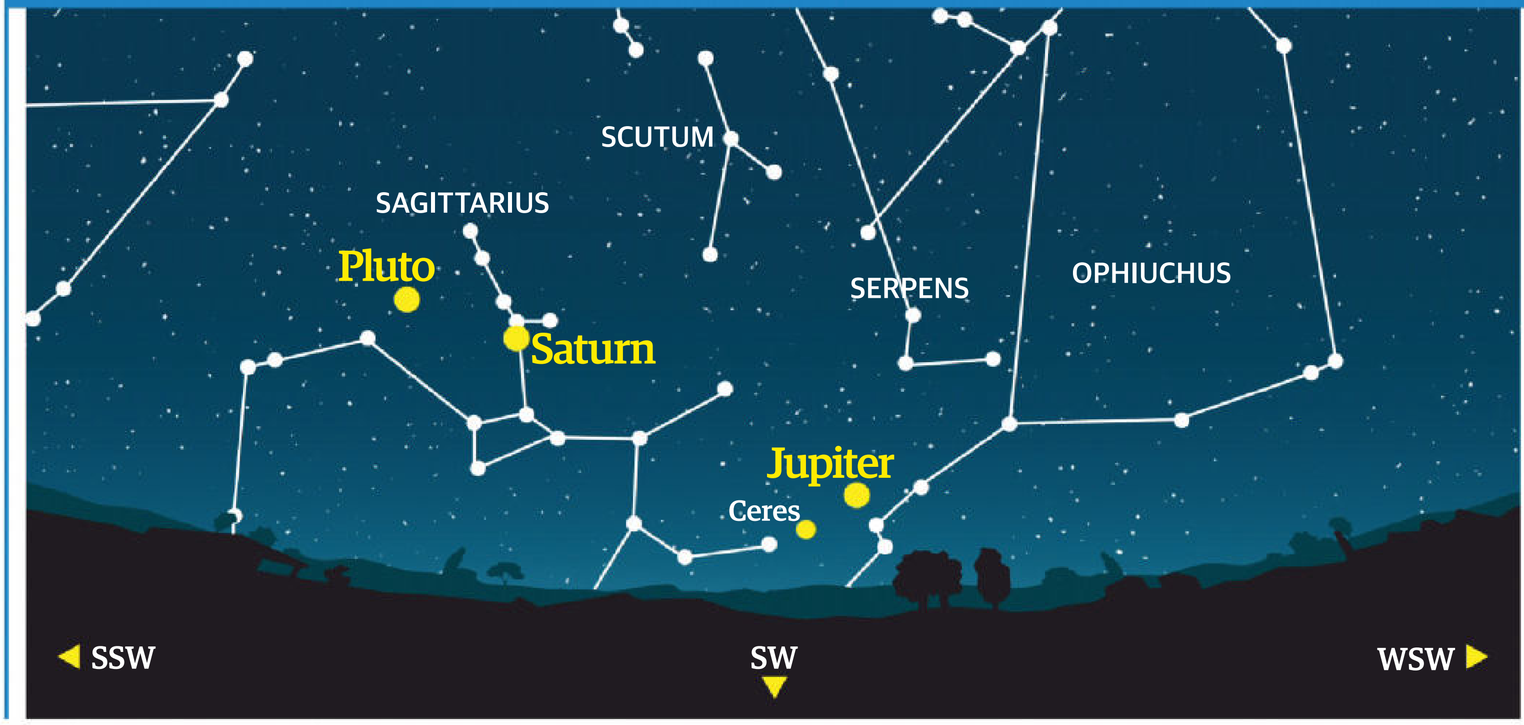
Venus 17:00 GMT on 29 October



Constellation: Virgo
Magnitude: -3.9
AM/PM: PM

Spotting Venus this month will be challenging, but by no means impossible. On clear, crisp, mid-October evenings you will find it shining low in the WSW after sunset, looking like a silvery spark fighting to be seen in the marmalade twilight. As the days pass Venus' visibility will improve slightly.

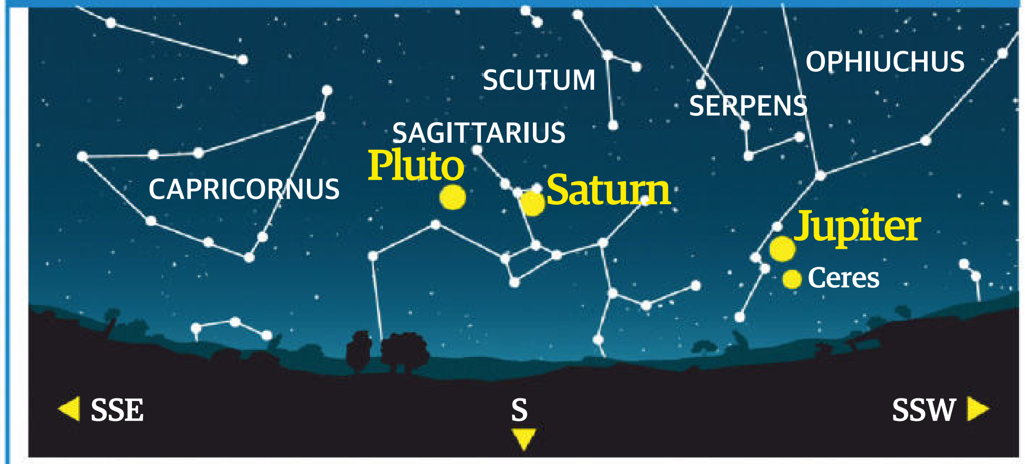
Jupiter 18:00 BST on 4 November



Constellation: Ophiuchus
Magnitude: -2.0
AM/PM: PM

Jupiter is very obvious throughout this month's observing period, easily visible to the naked eye. You'll see it low in the south as soon as the sky starts to darken after sunset, looking like a blue-white star over to the right of fainter Saturn and to the upper left of Venus. As the days pass Jupiter will set earlier each night, so best to start looking as early as you can. Look out for a beautiful crescent Moon shining a short distance away to Jupiter's lower right in the twilight on 30 October, and just one-and-a-half Moon widths away from it the following evening – a stunning sight in binoculars or a small telescope.

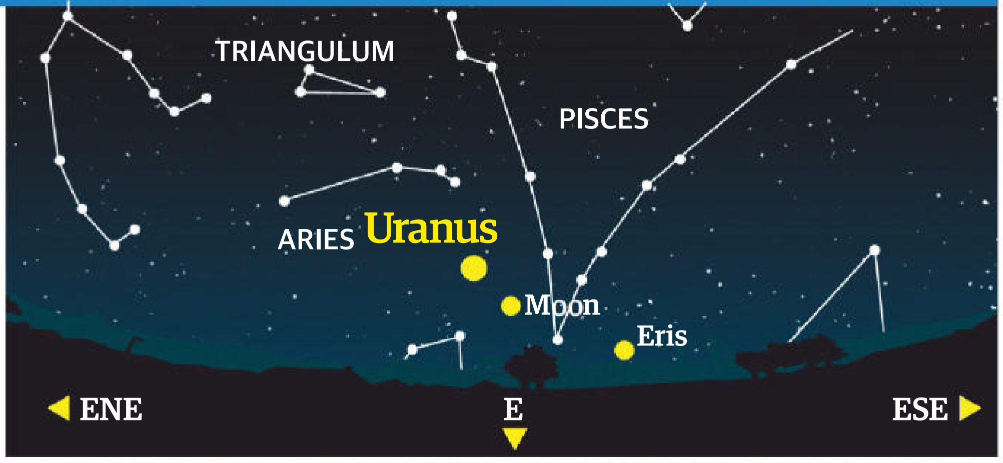
Saturn 19:00 BST on 15 October



Constellation: Sagittarius
Magnitude: 0.5
AM/PM: PM

Saturn is probably the easiest planet to see this month. Easily visible to the naked eye, it will look like a yellow-white 'star' shining a short distance to the upper left of the handle of the famous 'Teapot' asterism in Sagittarius. You'll be able to see it shining low in the south as soon as the sky begins to darken after sunset.

Uranus 20:00 BST on 14 October



Constellation: Aries
Magnitude: 5.7
AM/PM: PM

Shining – if that's the right word to use – at magnitude 5.7, Uranus is technically a naked-eye object, but in reality it is very hard to find; magnitude 5.7 is right on the edge of naked-eye visibility, Look for the almost-full Moon shining around six degrees to Uranus' lower right after dark on 14 October.

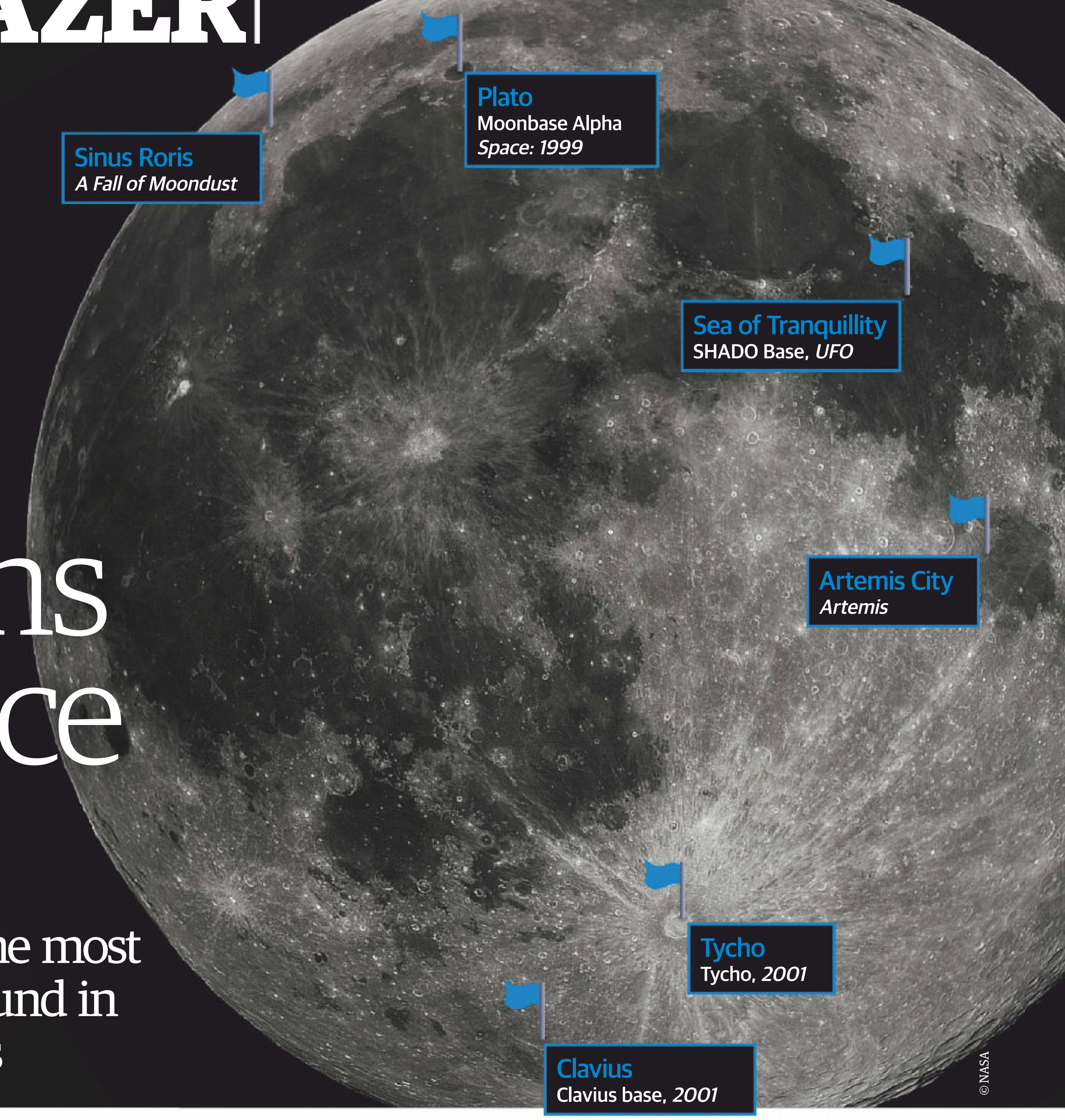
Top tip!

There are lots more stories set on the Moon, of course, so why not fire up the Moon map in your favourite astronomy app and track down the locations of some of them?

Moon tour

Locations of science fiction

Track down some of the most famous places to be found in the Moon's sci-fi stories



© NASA

The Moon has been a favourite destination of science-fiction writers, film-makers and TV series producers for as long as there have been books, films and TVs. In 1865 fantasy author Jules Verne's classic novel *From the Earth to the Moon* told the story of a group of post-American Civil War weapons engineers coming together to build a shell-shaped spaceship which carried three people to the Moon after being launched out of a giant cannon.

After World War II Hollywood began to explore the Moon too, and in 1950 the George Pal classic *Destination Moon* celebrated the hair-raising adventures of a private company and its astronauts making the first crewed landing on the Moon.

Since then the Moon has featured in too many books, films and TV shows to count - not all of them classics by any means! However, a few really do stand out, and it's fun today to use binoculars and telescopes to hunt down the locations featured in them - we're going to point you towards some of them in our Moon Tour this month.

First, the 1968 film *2001: A Space Odyssey* features not one but two famous lunar locations. At the start of the film Dr Heywood Floyd is seen travelling to a beautiful, rotating, ring-shaped space station in a sleek space shuttle with *The Blue Danube* playing in the background, before departing for the Moon on board a rather less glamourous-looking but much more functional lunar shuttle. Upon his arrival he descends to a sprawling Moon base complete with its own spaceport, tower blocks and conference rooms. This is Clavius Base, and as its name suggests it can be found within the crater Clavius. Clavius can be found down to the bottom of the Moon's disc, below and to the left of the crater Tycho and its bright rays.

Tycho crater itself is the second location featured in *2001*. Floyd travels from Clavius Base to Tycho to see for himself a strange artefact that has been discovered beneath that crater: a black monolith, left there by an alien intelligence millions of years before. Tycho crater is one of the easiest features to find on the Moon, especially near full Moon when its bright rays spray away from it for miles like paint or chalk dust.

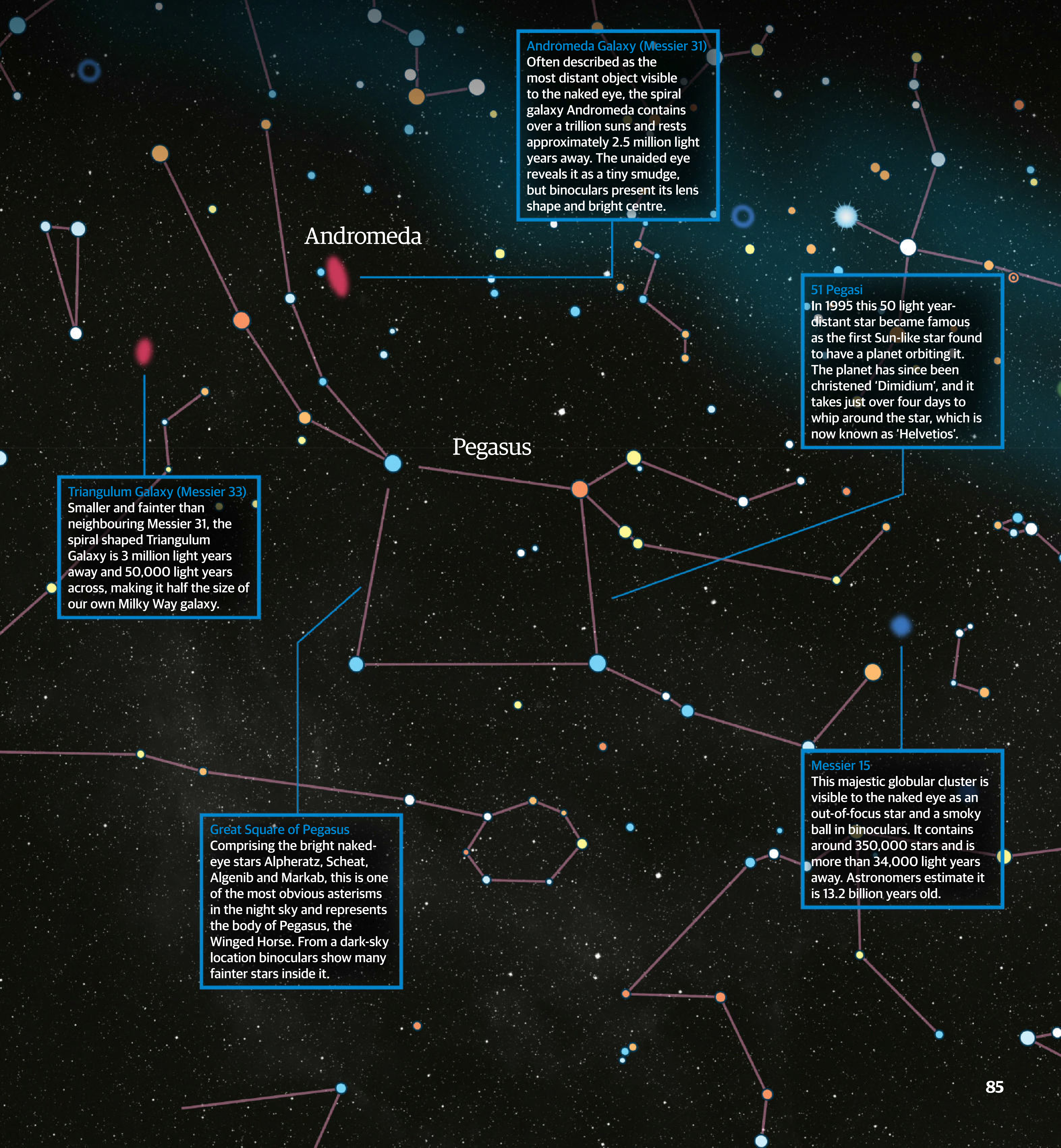
Moving on to sci-fi literature, one of the most famous - and best - novels written about life on a colonised Moon is *A Fall of Moondust* by Arthur C. Clarke. In this beloved 1961 book, the 'Selene', a vehicle that carries tourists across the lunar seas, gets trapped in a quicksand-like pool of moondust. Only the quick thinking and heroism of the Selene's brave young captain and its plucky chief stewardess save the day. The action takes place in Sinus Roris, a minor sea that can be found very close to the top limb of the Moon, looking like a long, dark patch just above the curved, cut-out basin of Sinus Iridium.

Moving on to TV, fans of Gerry Anderson will be aware that not one but two of his groundbreaking TV series featured locations on the Moon. Between 1970 and 1973 *UFO* showed brave members of the top-secret organisation SHADO - some dressed in very sparkly purple wigs - coordinating efforts to prevent attacks by sinister aliens from their Moon base in the Sea of Tranquillity, not far from the historic landing site of Apollo 11. Years later, *Space: 1999* had another Moon base, this time a huge one, four-kilometres (2.5-miles) wide and a kilometre (0.62-miles) deep. Moonbase Alpha - which looked very similar to *2001*'s Clavius Base - was constructed inside Plato crater, one of the most prominent features on the Moon, which can be found to the right of Sinus Iridium, up near the top limb of the Moon. In *Space: 1999* the Moon is famously blasted out of Earth's orbit and flung off on a journey to the stars after nuclear waste stored on the Moon's 'dark side' explodes in spectacular style.

Finally on this tour of amazing sci-fi places we return to the Sea of Tranquillity. Andy Weir followed up his hugely successful novel *The Martian* with *Artemis*, a story set on the Moon in the sprawling city of Artemis, population 2,000, which, like SHADO's secret Moon base, can be found close to the Eagle's landing site.

Naked eye & binocular targets

Look towards Pegasus and Andromeda to see a misty star cluster, an alien solar system and galaxies far, far away



Andromeda Galaxy (Messier 31)
Often described as the most distant object visible to the naked eye, the spiral galaxy Andromeda contains over a trillion suns and rests approximately 2.5 million light years away. The unaided eye reveals it as a tiny smudge, but binoculars present its lens shape and bright centre.

51 Pegasi
In 1995 this 50 light year-distant star became famous as the first Sun-like star found to have a planet orbiting it. The planet has since been christened 'Dimidium', and it takes just over four days to whip around the star, which is now known as 'Helvetios'.

Triangulum Galaxy (Messier 33)
Smaller and fainter than neighbouring Messier 31, the spiral shaped Triangulum Galaxy is 3 million light years away and 50,000 light years across, making it half the size of our own Milky Way galaxy.

Great Square of Pegasus
Comprising the bright naked-eye stars Alpheratz, Scheat, Algenib and Markab, this is one of the most obvious asterisms in the night sky and represents the body of Pegasus, the Winged Horse. From a dark-sky location binoculars show many fainter stars inside it.

Messier 15
This majestic globular cluster is visible to the naked eye as an out-of-focus star and a smoky ball in binoculars. It contains around 350,000 stars and is more than 34,000 light years away. Astronomers estimate it is 13.2 billion years old.

NGC 7479

© Wiki

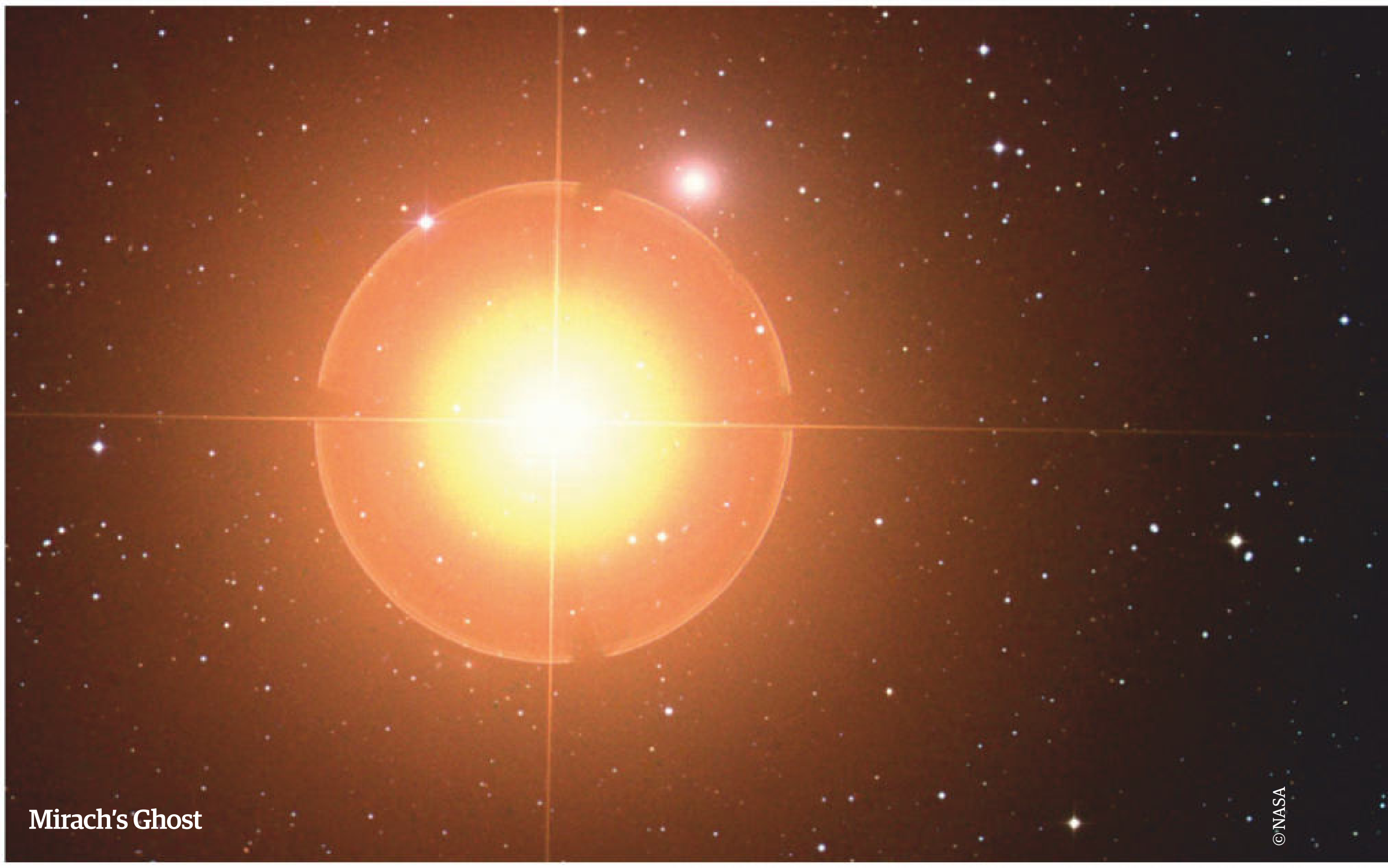
Deep sky challenge

Autumn around the flying horse

Gorgeous galaxies for cooler, crisp nights

Now autumn is truly here and the dark nights have finally returned, it's time to start looking deep, deep into space, through the starry veil of our own Milky Way galaxy at some of the wonders that lie beyond its boundaries. Looking towards Pegasus means looking up out of the plane of our galaxy, away from the nebulae and star clusters embedded in its frothy spiral arms and out into intergalactic space. This month's challenges are all faraway galaxies that might not be among the faintest deep-sky objects known, but are all quite close to each other in the sky, which allows you to go on a galactic tour without having to swing your telescope around in too many different directions.

The highlight of this month's tour is NGC 7479, which can be seen through small telescopes, but the more aperture you have the more detail you will see in its spiral arms, which really are beautiful at high magnification on a still, dark night. The Cassiopean pair of NGC 185 and NGC 147 might not be particularly thrilling individually, but like the more famous M81 and M82 in Ursa Major, they are close enough together to offer a very pleasing sight in a large telescope's eyepiece.



Mirach's Ghost

© NASA

Andromeda Galaxy (M31) and Messier 110

© Wiki

1 Mirach's Ghost (NGC 404)

This tenth-magnitude elliptical galaxy is almost overwhelmed by the glare of nearby Mirach, but a medium- or large-aperture telescope will reveal it as a diffuse smudge.

2 The Little Sombrero (NGC 7814)

Medium-aperture instruments will show this almost edge-on spiral galaxy as a faintly glowing needle of light. Larger telescopes show its brighter centre.

3 NGC 7479

This very pretty barred-spiral galaxy, presented almost face-on to us, is 11th magnitude, so seeing its gracefully curved arms requires a large telescope under a dark sky.

4 Messier 110

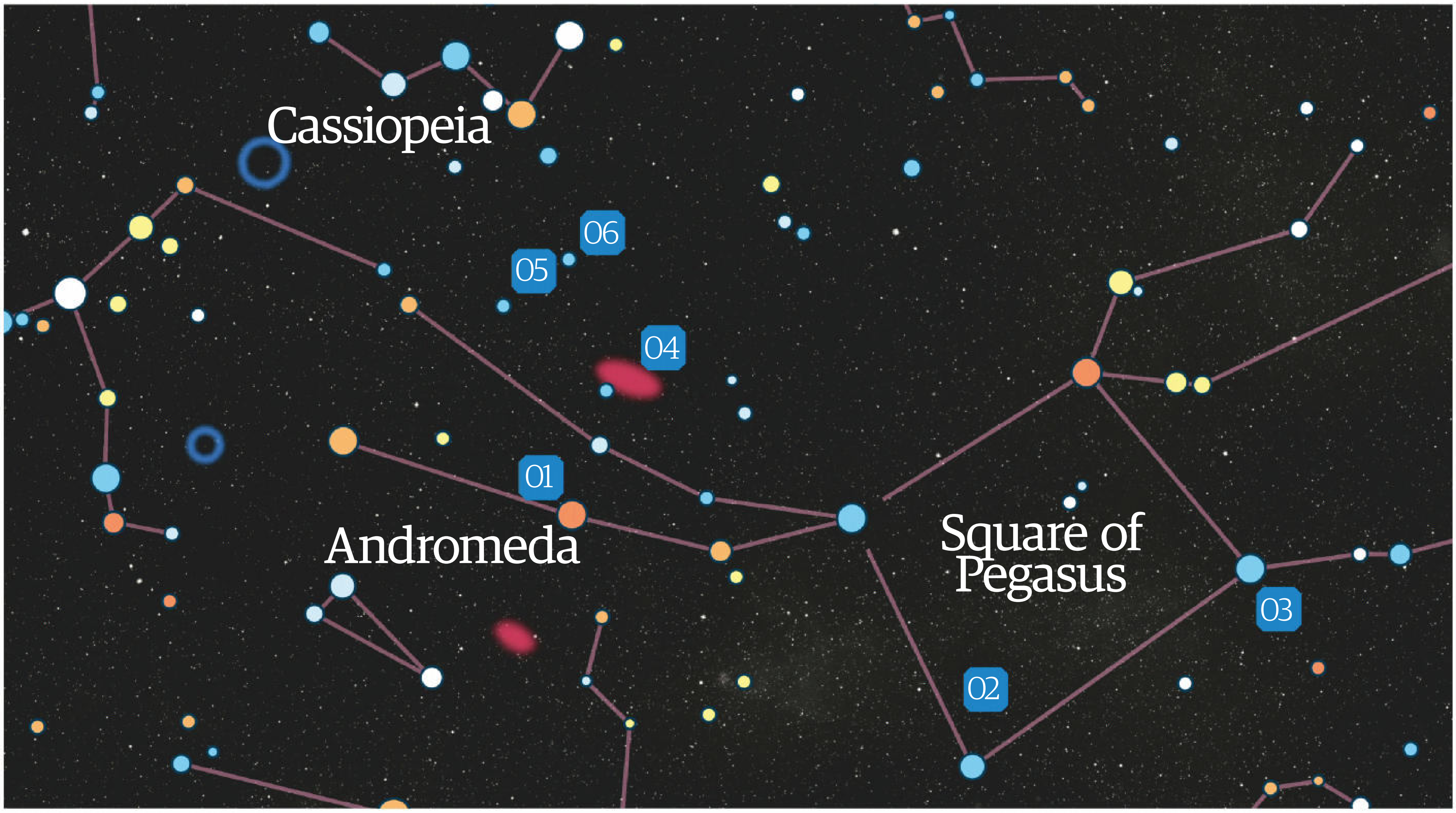
Being so close to M31, this elliptical galaxy is often overlooked, but it is a fine object in its own right. Large instruments will show its bright centre surrounded by a haze of stars.

5 NGC 185

Another satellite of M31, this dwarf elliptical galaxy forms a close pair with NGC 147. It is a mottled, small smudge with a bright centre through a large telescope's high-power eyepiece.

6 NGC 147

Lying just a degree away from NGC 185, this dwarf galaxy is half a degree fainter and is also a distant satellite galaxy of M31. Large instruments show it as a faint, elongated patch of light.



© Wil Tirion

The Northern Hemisphere

The clocks go back at the end of this month, giving more time to view a splendour of night-sky objects

Andromeda, Cassiopeia and Sculptor are just some of the constellations offering a selection of targets for telescope- and binocular-wielding astronomers this month. With the Sun dipping below the horizon earlier in the evening, those wanting to catch new or favourite targets don't have to wait long for dark skies to boast these treasures.

Head over to Andromeda and you'll be rewarded with not just its spiral galaxy, M31, but also its dwarf elliptical galaxies M32 and M110. While the parent galaxy is easy to spot, you'll need at least a medium-sized telescope to spot Andromeda's satellites. Star clusters are a joy to behold in the constellation of Cassiopeia, which can be spotted with ease by its 'W'.

Using the sky chart

This chart is for use at 22:00 (GMT) mid-month and is set for 52° latitude.

01 Hold the chart above your head with the bottom of the page in front of you.

02 Face south and notice that north on the chart is behind you.

03 The constellations on the chart should now match what you see in the sky.

Magnitudes

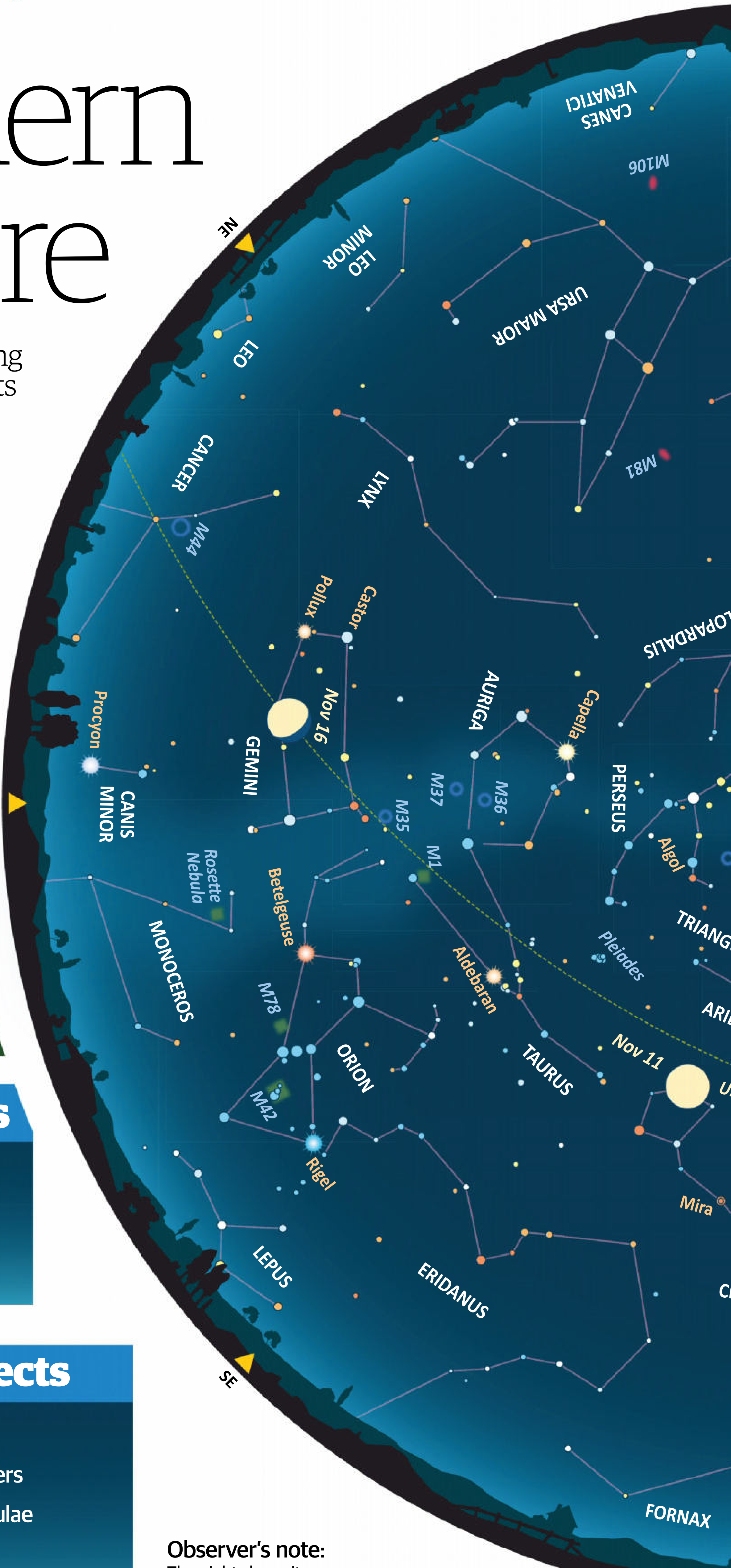
- ● Sirius (-1.4)
- ● -0.5 to 0.0
- ● 0.0 to 0.5
- ● 0.5 to 1.0
- ● 1.0 to 1.5
- • 1.5 to 2.0
- • 2.0 to 2.5
- • 2.5 to 3.0
- • 3.0 to 3.5
- · 3.5 to 4.0
- · 4.0 to 4.5
- · Fainter
- ◉ Variable star

Spectral types

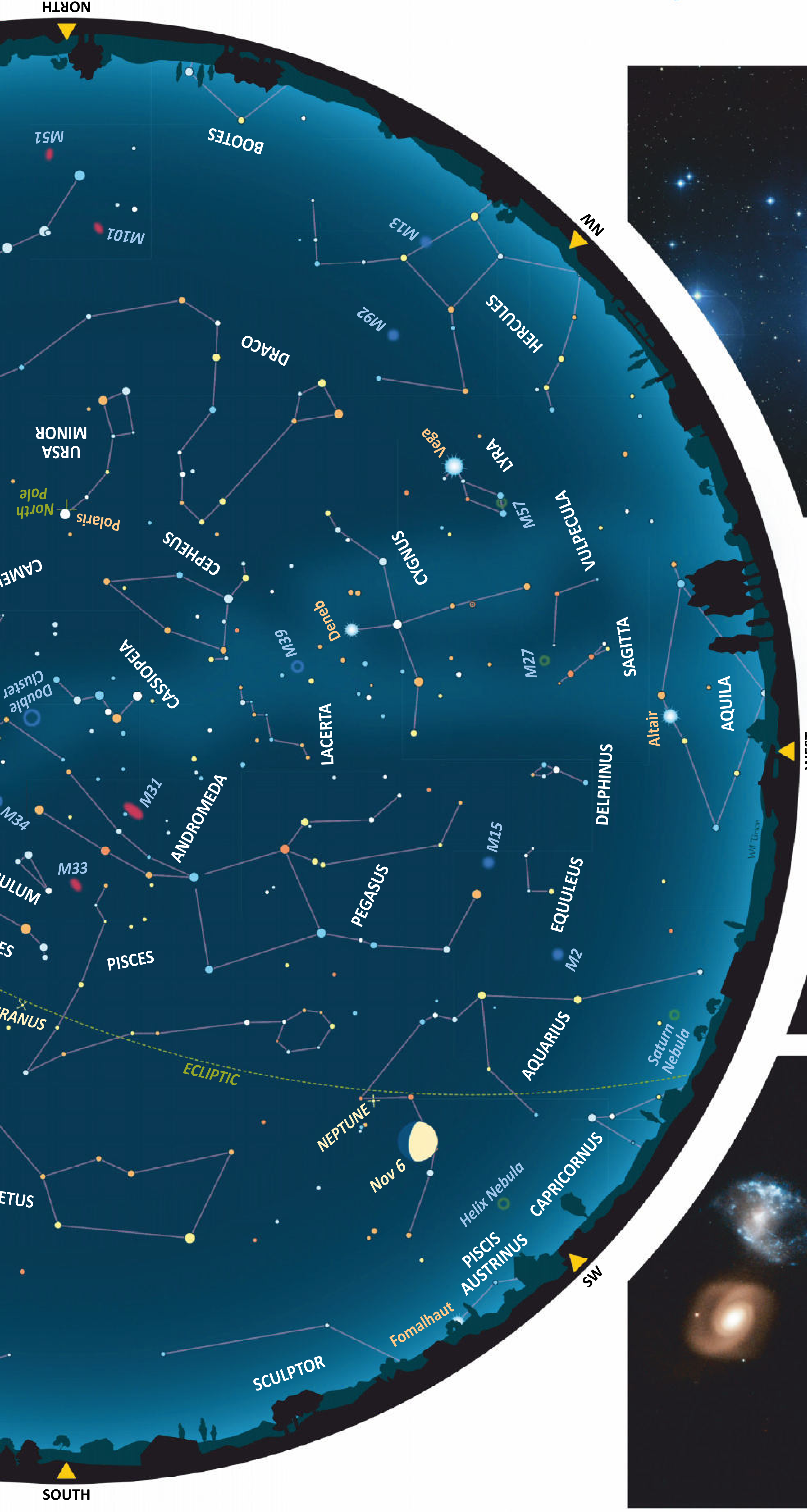
●	O-B	●	G
●	A	●	K
●	F	●	M

Deep-sky objects

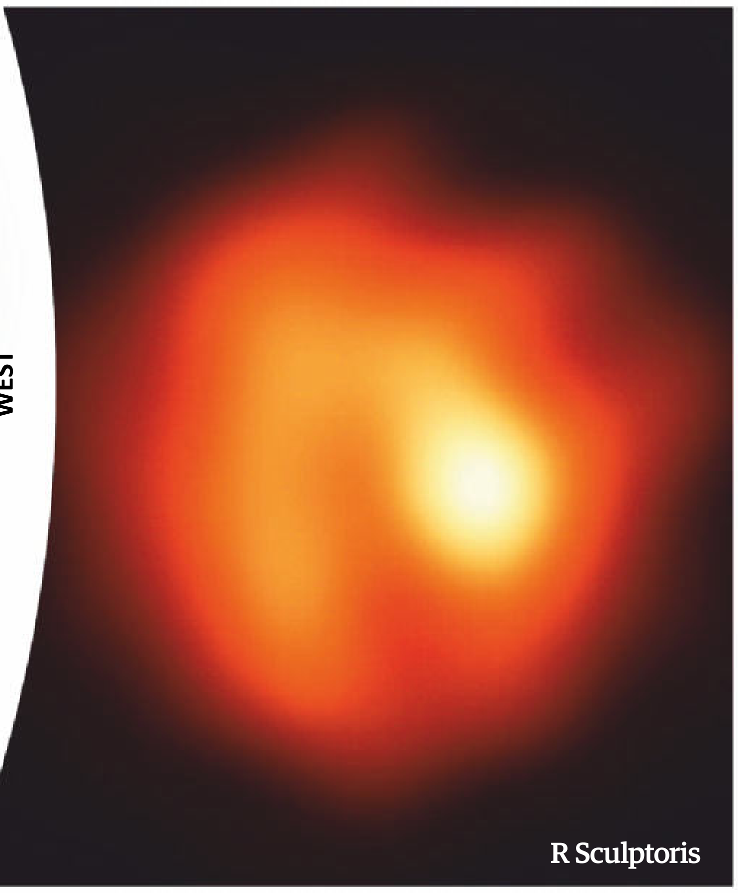
- ○ Open star clusters
- ● Globular star clusters
- ■ Bright diffuse nebulae
- ○ Planetary nebulae
- ⬬ Galaxies

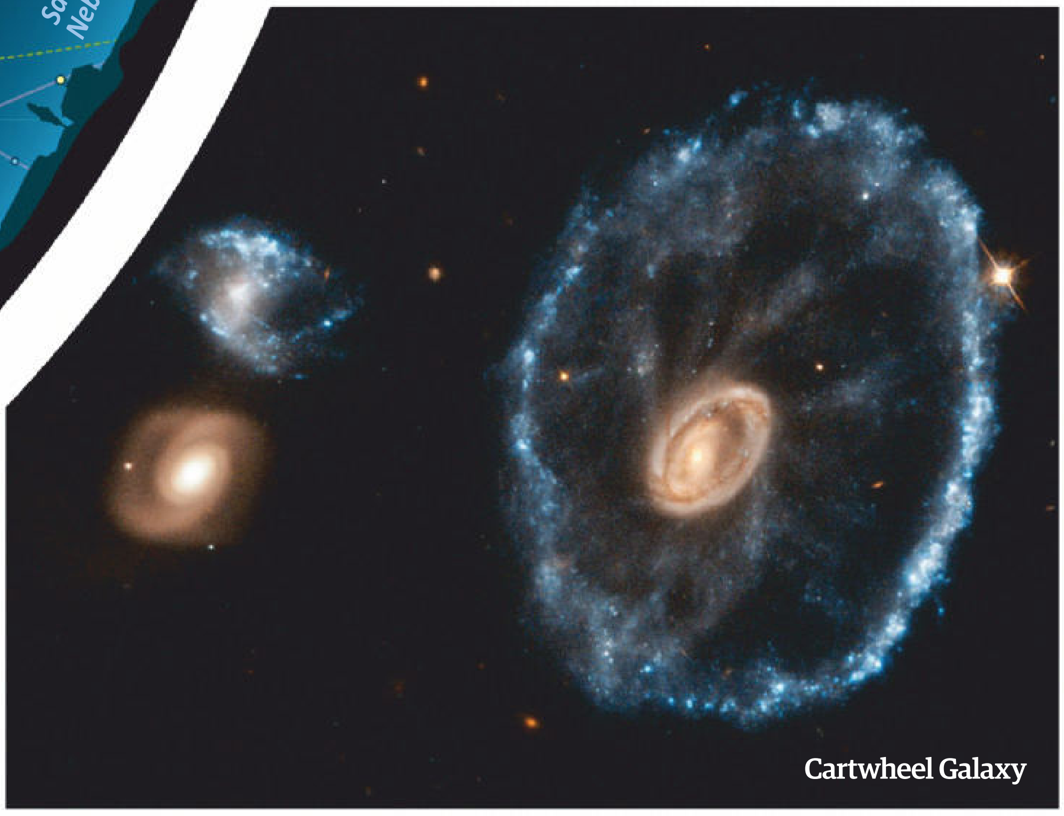


Observer's note:
The night sky as it appears on 17 November 2019 at approximately 22:00 (GMT)



The Pleiades (Messier 45)


R Sculptoris


Cartwheel Galaxy

© Wiki

Astroshots of the month

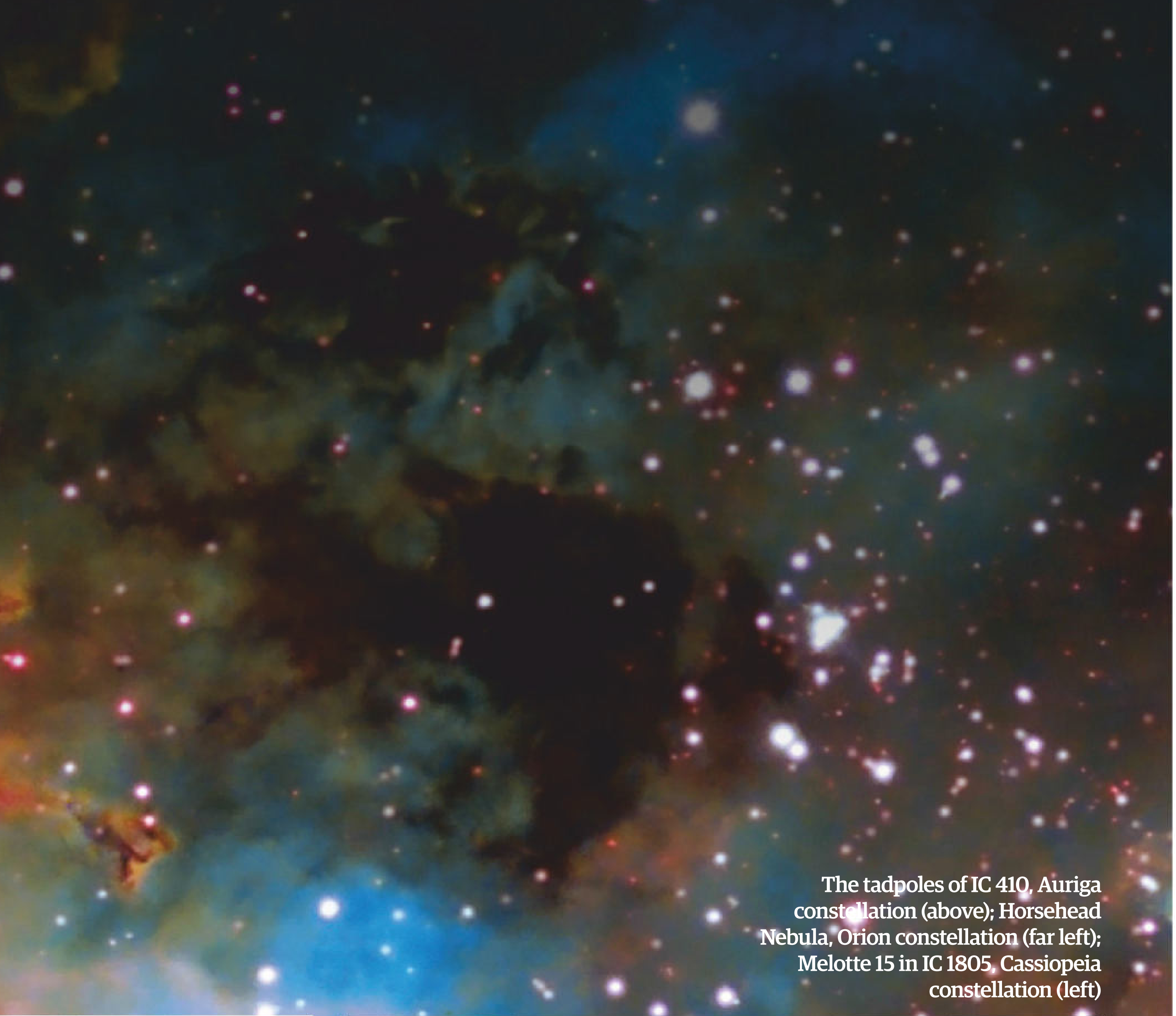
Send your astrophotography images to **space@spaceanswers.com** for a chance to see them featured in **All About Space**

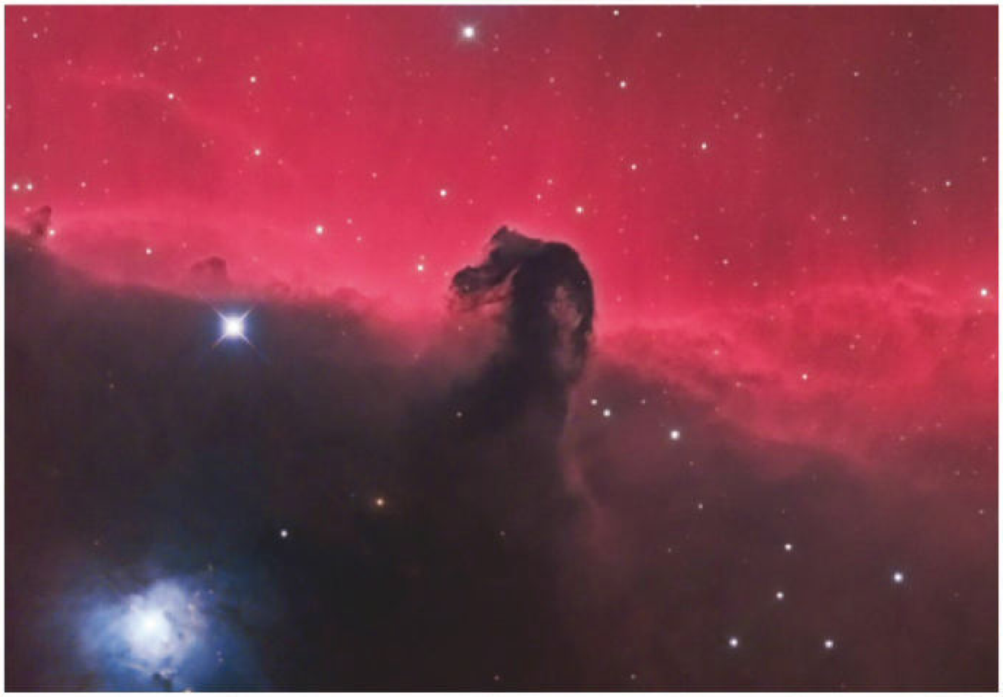
Steve Coates

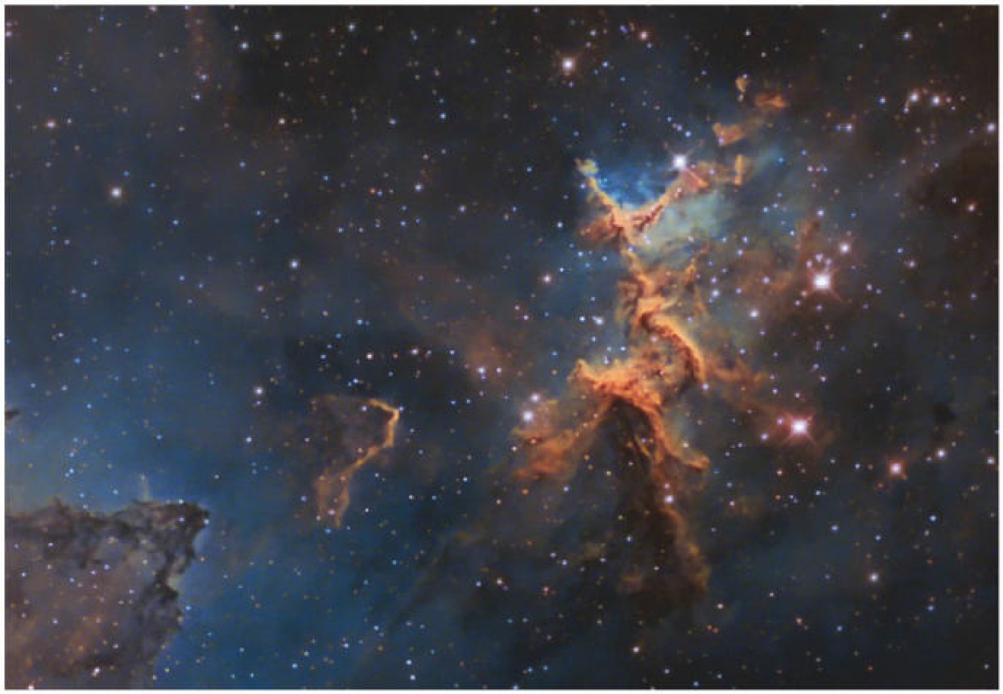
Ocala, Florida

Telescope: Eight-inch Ritchey-Chrétien

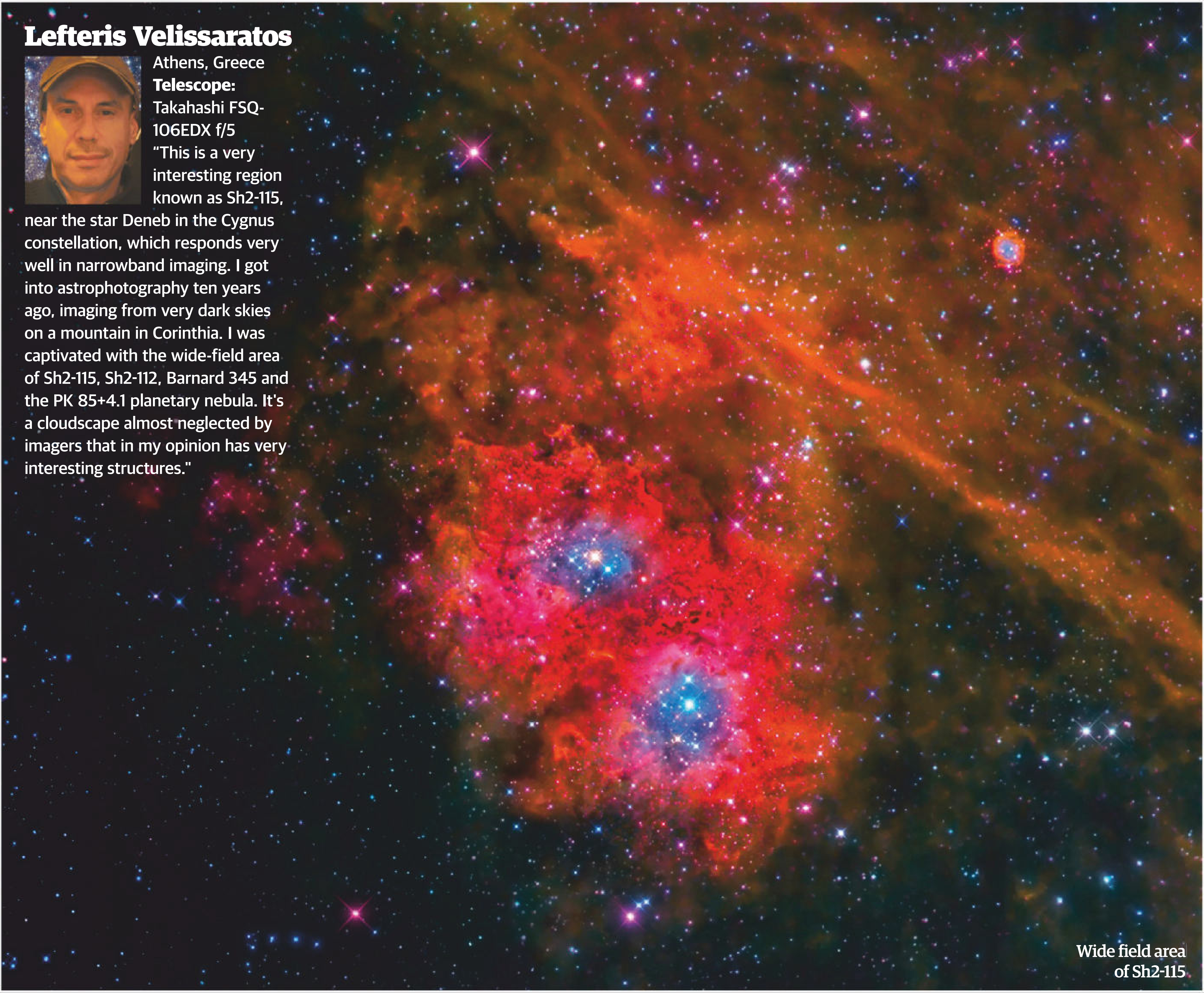
"I started my hobby in astronomy when I bought an eight-inch Sky-Watcher SCT in July 2009. I started imaging in January 2010 using a Nikon D40 and I now use a cooled QSI CCD camera when I image from my light-polluted backyard in central Florida. These images were taken using a QSI 683 WSG-8 cooled CCD camera and an eight-inch Ritchey-Chrétien with a focal length of 1,625mm. I took these images using four different filters: hydrogen-alpha for detail and RGB filters for colour."







The tadpoles of IC 410, Auriga constellation (above); Horsehead Nebula, Orion constellation (far left); Melotte 15 in IC 1805, Cassiopeia constellation (left)



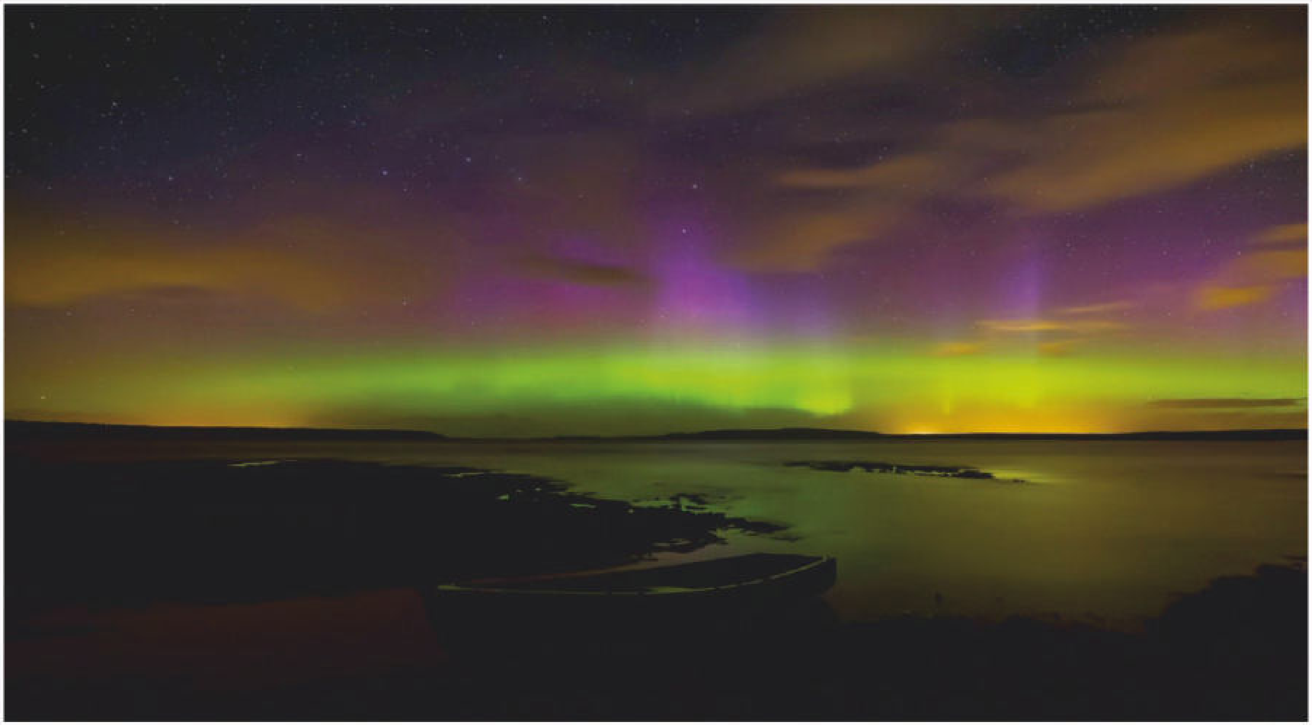
Lefteris Velissaratos

Athens, Greece

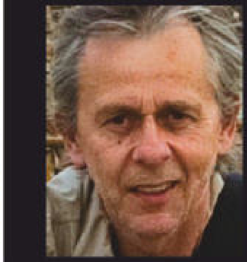
Telescope: Takahashi FSQ-106EDX f/5

"This is a very interesting region known as Sh2-115, near the star Deneb in the Cygnus constellation, which responds very well in narrowband imaging. I got into astrophotography ten years ago, imaging from very dark skies on a mountain in Corinthia. I was captivated with the wide-field area of Sh2-115, Sh2-112, Barnard 345 and the PK 85+4.1 planetary nebula. It's a cloudscape almost neglected by imagers that in my opinion has very interesting structures."

Wide field area of Sh2-115



Stewart Watt



Caithness, Scotland

"This aurora shot was taken from Caithness in the last couple of years. As we don't have the stunning aurora displays they get in the Arctic Circle, composition of the shots perhaps takes on more importance to achieve better results, so if possible I always try to get some good foreground interest rather than just the green and purple hues of the aurora itself.

Sadly this solar maximum has been very weak, with intensity and frequency well down on previous cycles. Nonetheless, whenever there is a CME [coronal mass ejection] released from the Sun, or a coronal hole opens up, the hope that the next display might be a spectacular one keeps the cold at bay as we stand on a remote headland in the middle of winter, bombarded by gales and showers. Maybe we're just a little crazy."

Send your photos to... @spaceanswers @ space@spaceanswers.com

Meade Infinity 80AZ

An attractive and reasonably priced telescope for the beginner, this refractor comes with everything you need to break into the hobby of astronomy

Telescope advice

Cost: £120 / $189.99
From: Hama UK Ltd
Type: Refractor
Aperture: 3.2"
Focal length: 15.8"

Best for...

- Beginners
- Small budget
- Planetary viewing
- Lunar viewing
- Bright deep-sky
- Basic astrophotography

For its retail price, we were impressed with the build of the Meade Infinity 80AZ, along with its performance, when we took the instrument out for a night of observations on an August evening. Unpacking the refractor, we noted that the telescope comes very well-equipped with three eyepieces for low, medium and high magnification and a Barlow lens, as well as a DVD that provides instructions on how to set up the telescope. We were pleased with the addition of planetarium software that advises on over 10,000 celestial objects in the night sky up for observation at different times of the year – however, we would note that you won't be able to observe all of these objects due to the telescope's small aperture.

While instructions are provided, we felt that setting up the Infinity 80AZ was very intuitive, and within ten minutes the refractor was built and ready to use, making it an ideal instrument for those just breaking into the hobby of astronomy. From an aesthetic point of view, we enjoyed the beautiful finish of the telescope's tube – a striking metallic blue that certainly makes it stand out from the more-muted black that is common with telescopes. The 80AZ has a great deal of plastic on it, but Meade has ensured us that the refractor is robust enough to withstand wear and tear. Nevertheless, we advise treating the instrument with care.

With its three-inch aperture, we took advantage of the Moon in its waxing crescent phase, where the terminator made an ideal guide to find a selection of craters and lunar mare. The red dot finder worked extremely well as we located the craters Langrenus and Stevinus with ease before following the terminator and appreciating the Infinity 80AZ's efforts in picking out Tycho's brilliant ray system. Moving towards the Sea of Crises and the Sea of Fertility, which popped out with their characteristic grey shading against the chalky white lunar highlands, we headed towards the Moon's limb.

As previously mentioned, the refractor comes with three-element eyepieces with focal lengths of 6.3mm, 9mm and 26mm. These are of good quality with anti-reflection, fully coated optics and fold-down rubber eyecups, which gave fair eye relief. While our overall views of the Moon were crystal clear, there was a very obvious degree of colour fringing, also known as chromatic aberration, which took the form of a purple-blue glow around the Moon's edges. Despite this fault, we have to say that the views of the lunar surface were very sharp.

The telescope's red dot finder did exactly as required, allowing us to find our way not just around the Moon's surface but also around the night sky as we continued our tour. However, when we were bringing targets of interest into focus in the refractor's

Below left: For the price the optical system operated very well and provided reasonable views – sadly though, there was a degree of colour fringing

Below right: The Meade Infinity 80AZ comes with three eyepieces – 6.3mm, 9mm and 26mm – with anti-reflection fully coated optics and fold-down rubber eyecups

field of view, the mount did shake, making the target of interest dance around the field too. In order to achieve a steady view, we were forced to turn the focus knob bit by bit.

Sweeping the telescope across a September sky, we were able to star-hop from one target to the next – this is a very important method for the beginner astronomer to find their way around the heavens. However, the highlight of our review of the Infinity 80AZ was a spectacular view of Saturn, which appeared as a first-magnitude star to the naked eye. It quickly became our object of interest in trying out the refractor. The planet's majestic rings were titled 24 degrees towards the Earth and through this small telescope we achieved a small but good view of the gas giant.

The Meade Infinity 80AZ is ideal for those just breaking into astronomy. If you're looking to expand your hobby and set your sights on fainter deep-sky objects, then you are better off looking for a telescope with a larger aperture. For an entry-level telescope though, or a starter telescope for children, we certainly think that this is a good, reasonably priced refractor. Other instruments at a similar price point have either come with limited accessories or have been too 'toy-like' for decent views of our Solar System – this scope is certainly ahead of the pack.

Right: The Meade Infinity 80AZ is a telescope that's ideal for the family – especially beginners and children

Below: The tripod supported the telescope tube and mount substantially as we toured the night sky, but did shake when we brought targets into focus

WORTH £250!

WIN MEADE POLARIS 114 REFLECTOR

Perfect for both beginners and more advanced users, this telescope presents some of the sky's finest Solar System and deep-sky targets

Reveal the wonders of the cosmos with the slew of a telescope tube. This Meade 114-millimetre (4.5-inch) equatorial reflector telescope is a great place to start if you're new to observational astronomy or need a 'grab-and-go' instrument for those quick views of the night sky.

You don't just get a telescope in the package – it also comes with three eyepieces, two Barlow lenses and an accessory tray, as well as an Autostar Suite Astronomy DVD. The Meade Polaris 114 provides easy access to a wide array of celestial objects, whether it's Sirius twinkling in Canis Major, the fabulous Cat's Eye Nebula or even our neighbouring spiral, the Andromeda Galaxy. The refractor's lightweight design and ease of assembly mean that you spend more time gazing upon the wonders of the night sky than setting up.

To be in with the chance of winning, all you have to do is answer this question:

Which of these planets doesn't have any moons?

A: Jupiter

B: Mars

C: Venus

Competition ends on 2 November 2019

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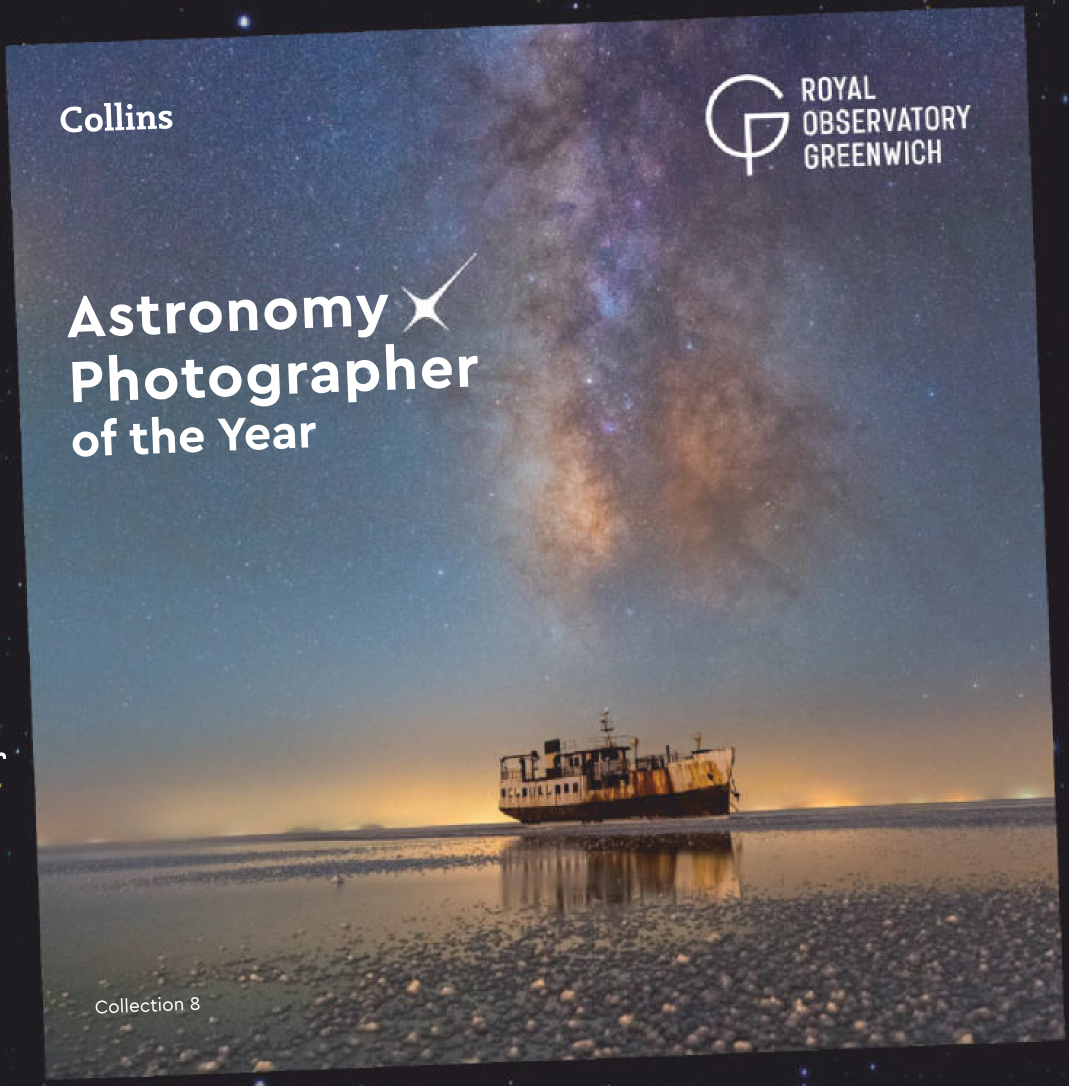
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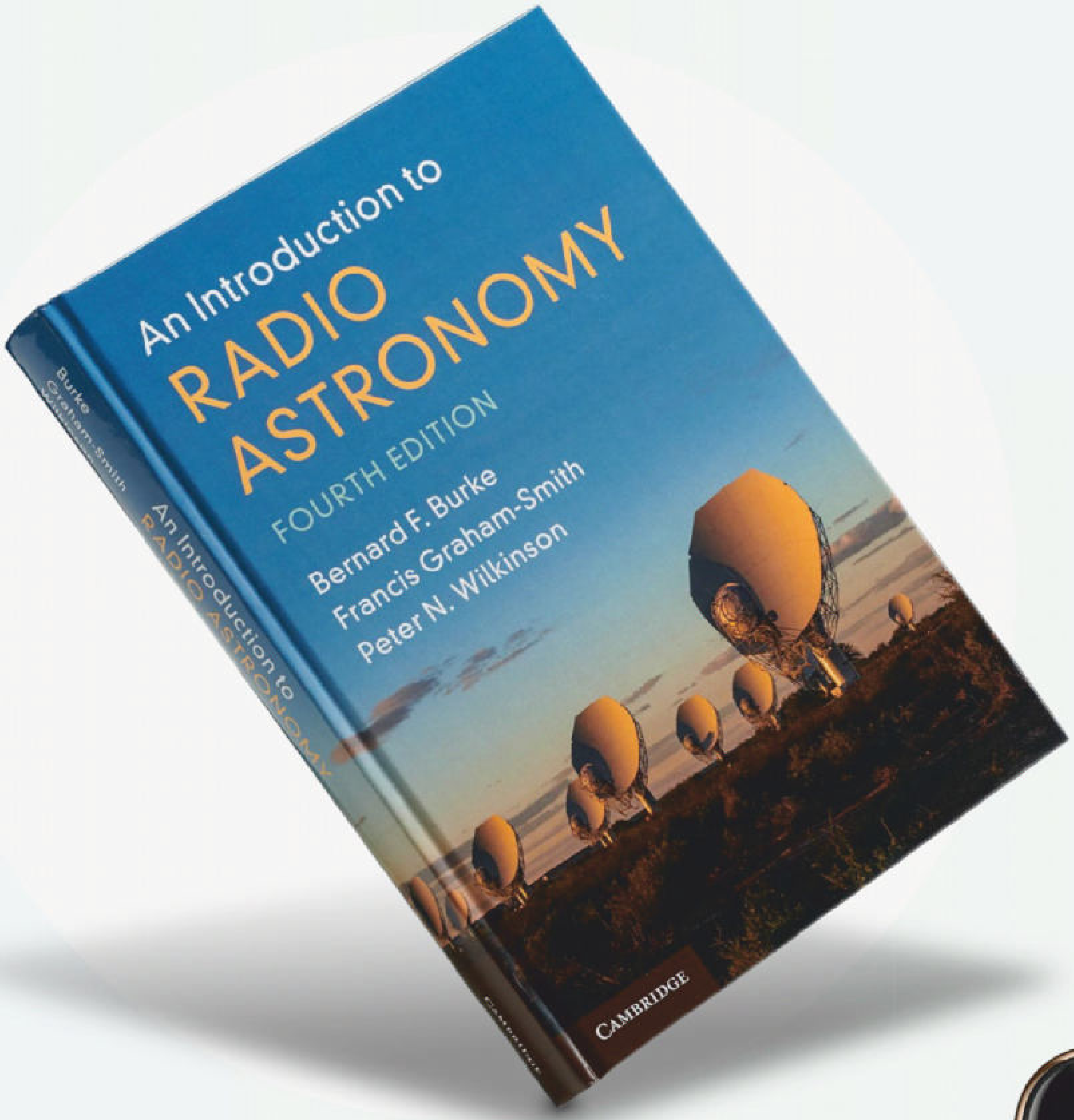


Book

An Introduction to Radio Astronomy

Cost: £59.99 (hardback)
From: Cambridge University Press

Radio astronomy is an active and rapidly expanding field due to advances in computing techniques, with several important new instruments on the horizon. This text provides a thorough introduction to radio astronomy and its contribution to our understanding of the universe, bridging the gap between basic introductions and research-level treatments. It begins by covering the fundamentals physics of radio techniques, before moving on to single-dish telescopes and aperture synthesis arrays. Fully updated and extensively rewritten, the fourth edition places greater emphasis on techniques, with detailed discussion of interferometry in particular, and comprehensive coverage of digital techniques in the appendices. The science sections are fully revised, with new author Peter N. Wilkinson bringing added expertise to the sections on pulsars, quasars and active galaxies. Spanning the entirety of radio astronomy, this is an engaging introduction for students and researchers approaching this observational field for the first time.

App

Star Walk 2

Cost: £1.99/$3.40
From: iTunes

If you have difficulty finding your way around the night sky and you can't afford a GoTo, then Star Walk 2 is the next best thing since it's able to work out the exact location as well as the celestial object that you point your iPhone at. Like the original, Star Walk 2 works by pointing it at the sky to get a real-time view of celestial bodies. As you move it around the app constantly adjusts to show what is out there beyond Earth.

Of course, it works in reverse too, by helping you to find the object that you wish to locate. Using a GoTo, we followed up the RA and Dec coordinates to see how accurate it is and were impressed to find that, on harnessing the iPhone's GPS capabilities, it was almost spot on. There are several display options. You can change up how stark the constellations appear, either by drawing subtle lines between them or by using a more animated character. Star Walk 2 also adds in soothing space music and various sound effects, which you can toggle off if they are not to your liking. Visual effect choices are present for the atmosphere, horizon, and a body of water that floats across the screen. Star Walk is also augmented reality enabled.

© Apple Inc.

Globe

Jupiter MOVA Globe (4.5")

Cost: £185 (approx. $150)
From: MOVA International

Certainly a novel product, this rotating globe of gas giant Jupiter is a stunning addition to any space fan's household. The detail is exquisite, with the Jovian bands, the Great Red Spot and its white and brown ovals taking a true likeness of the king of the Solar System. The globe rotates when exposed to natural light and comes with a three-prong stand, which from a distance makes it appear that the globe is levitating.

Given that the globe is powered by light, there is no need to plug it in or insert batteries. This natural operation means that the globe rotates gently and silently. With such a fine amount of detail put into the planet, this product is much more expensive compared to a standard globe. Though the quality is very high, we do feel that MOVA could have reduced the white seam that runs about the globe's centre. This is an issue that that will show up even more on the planets with fewer features such as Neptune and Mars, also in the MOVA range.

This MOVA globe might be on the expensive side, but given its rarity, beauty and low maintenance, it is certainly worth splashing out on for yourself or any space fan.

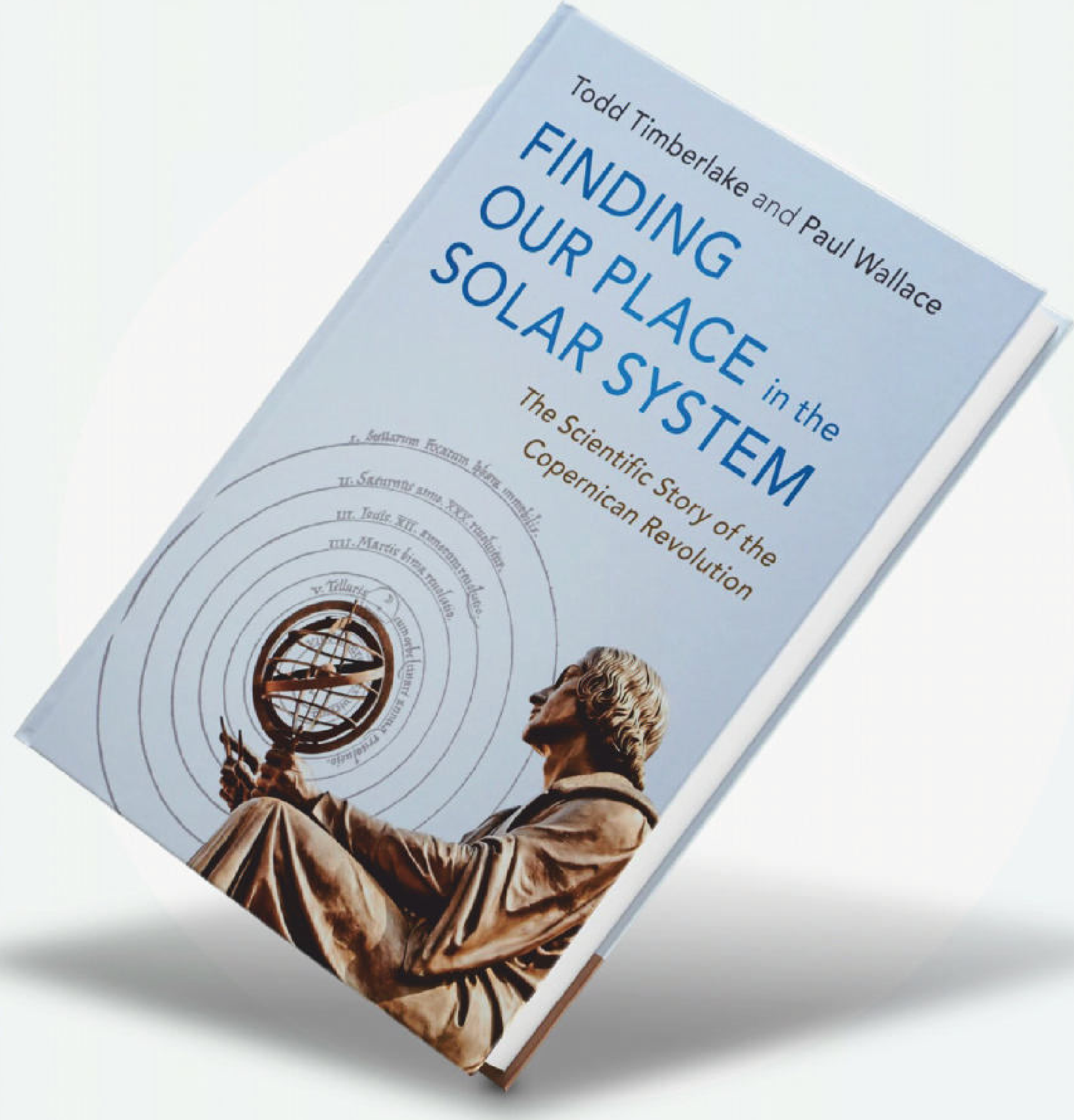
Book

Finding our place in the Solar System: The Scientific Story of the Copernican Revolution

Cost: £29.99 (hardback)
From: Cambridge University Press

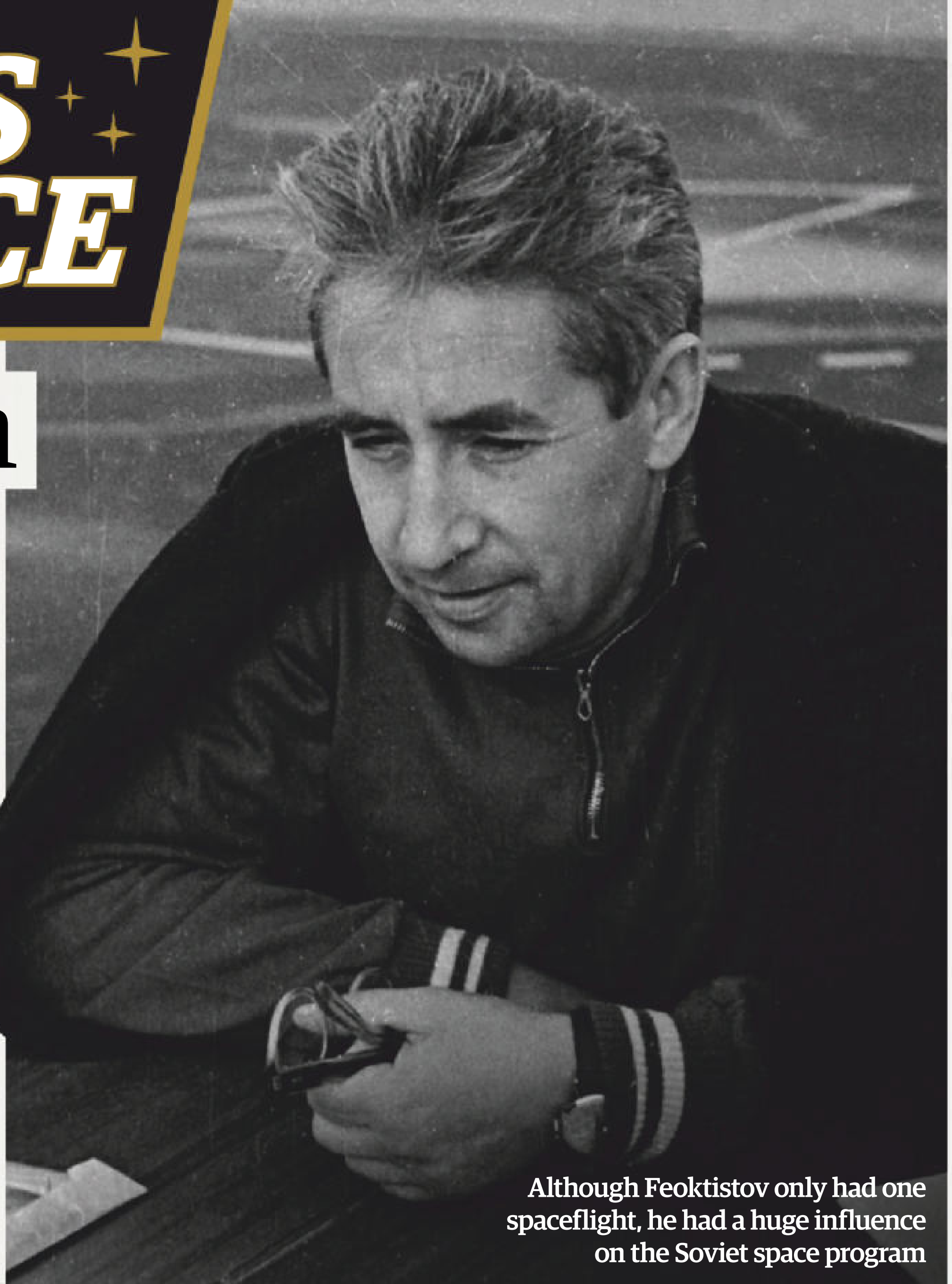
Finding our Place in the Solar System gives a detailed account of how the Earth was displaced from its traditional position at the centre of the universe to be recognised as one of several planets orbiting the Sun under the influence of a universal gravitational force. The transition from the ancient geocentric worldview to a modern understanding of planetary motion, often called the Copernican Revolution, is one of the great intellectual achievements of humankind.

This book provides a deep, yet accessible, explanation of the scientific disputes over our place in the solar system and the work of the great scientists who helped settle them. Readers will come away knowing not just that the Earth orbits the Sun, but why we believe that it does so. The Copernican Revolution also provides an excellent case study of what science is and how it works.


Todd Timberlake and Paul Wallace
FINDING OUR PLACE in the SOLAR SYSTEM
The Scientific Story of the Copernican Revolution

Konstantin Feoktistov

An engineer turned cosmonaut flew on the spacecraft he helped design



Although Feoktistov only had one spaceflight, he had a huge influence on the Soviet space program

© Alamy

This year marks the 55th anniversary of a milestone made by the Union of Soviet Socialist Republics' (USSR) space program, when Konstantin Feoktistov became the first civilian cosmonaut on board the Voskhod 1 mission. This was among many firsts the venture provided.

Born on 7 February 1926 in the city of Voronezh, formally Soviet Union and now part of Russia, Feoktistov had troublesome teenage years, having to fight against the Nazi occupation of Voronezh during World War II when he was just 16 years old. Afterwards he returned to school where he graduated from Bauman Moscow Higher Technical School with an engineering degree, then earning a doctorate in physics.

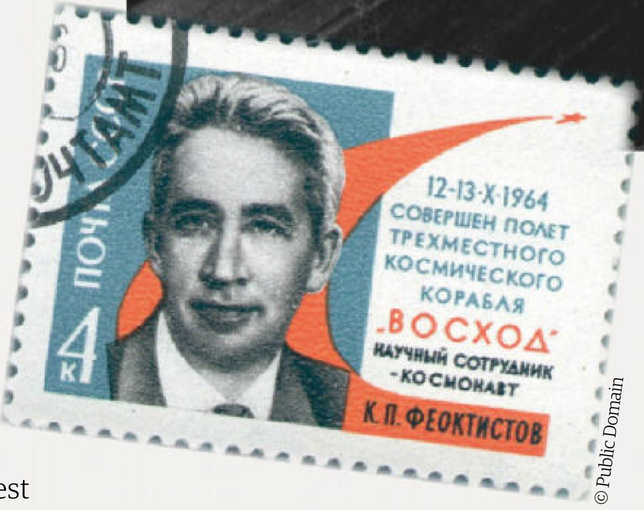
He would help design the Soviet space program's finest spacecraft, including the iconic Sputnik satellites and the Vostok, Voskhod and Soyuz space capsules. He has been credited as being second only to chief designer Sergei Korolev, a pivotal cog in the Soviet space program. In 1964 the Soviets selected a group of engineers for cosmonaut training, with Feoktistov being part of that group, and before he knew it he was assigned to the Voskhod 1 mission crew that very same year.

The Voskhod 1 mission was a mission of many firsts, being the first mission to feature more than one crewman, the first mission to not feature spacesuits and the first to use a multidisciplinary team, including an engineer/physicist and medical doctor. The main purpose of the mission was to test the craft's design - which Feoktistov had worked on - perform biomedical research and evaluate how a multidisciplinary team worked together. Feoktistov was the first Soviet civilian to go into space and the only cosmonaut in USSR history to not be a member of the Communist Party, which one can imagine caused much resistance in his eventual approval.

The mission's team consisted of Feoktistov; Vladimir Komarov, commander, and Boris Yegorov, a physician, and was launched from Baikonur Cosmodrome in Kazakhstan, also referred to as 'Gagarin's Start'. This was also the start of Voskhod 1's one-day adventure into space, where the craft recorded an altitude record - at the time - of 336 kilometres (209 miles). This milestone of a mission concluded Feoktistov and Yegorov's appearances in space, whereas Komarov would undertake one more mission, where he sadly became the first human to die in a spaceflight in 1967 on Soyuz 1.

Feoktistov campaigned to fly again, on the second Soyuz mission and to the Salyut space station that he had also helped design, but was refused because he did not meet the physical demands of a pilot. After this rejection he would still help design space stations, playing a role in the design of the famous Mir space station.

Sadly, on 21 November 2009, Roscosmos announced Feoktistov's death in Moscow, Russia. However, for all his efforts he received many accolades, which included the Hero of the Soviet Union award, an Order of Lenin award and many more - and he will forever be immortalised by the Feoktistov crater on the far side of the Moon.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Left: Feoktistov made an appearance on a Soviet stamp in 1964

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> "He would help design the Soviet space program's finest spacecraft, including the iconic Sputnik satellites"

All About Space

Future PLC Richmond House, 33 Richmond Hill, Bournemouth, Dorset, BH2 6EZ

Editorial
Editor-in-Chief **Gemma Lavender**
gemma.lavender@futurenet.com
Art Editor **Jonathan Wells**
Staff Writer **Lee Cavendish**
Production Editor **Nikole Robinson**
Research Editor **Baljeet Panesar**
Senior Art Editor **Duncan Crook**
Photography **Olly Curtis**

Contributors
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Account Manager **Jagdeep Maan**
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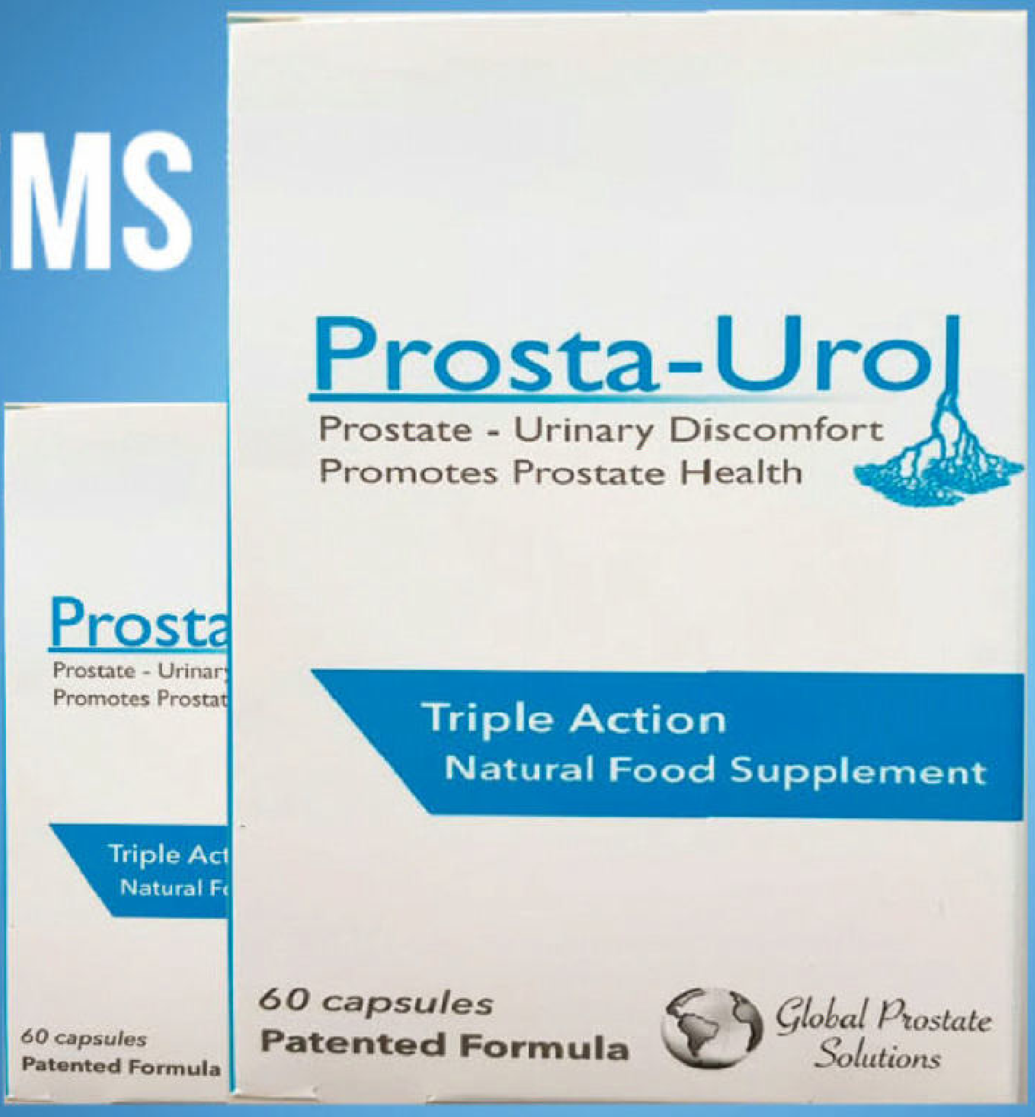

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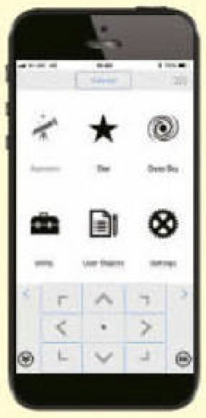

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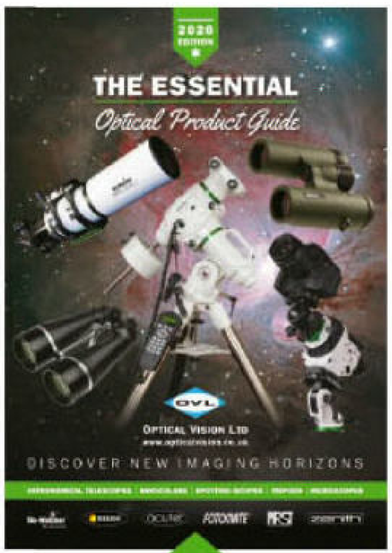

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